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ELF Communications System Ecological Monitoring Program: Wetland Studies – Final Report

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This report documents the results and conclusions of in situ studies designed to monitor for possible effects on wetland flora from exposure to electromagnetic (EM) fields produced by the U.S. Navy's Extremely Low Frequency (ELF) Communications System.

The studies examined for possible effects to herbs, shrubs, and trees growing on peat bogs near the Navy's Wisconsin Transmitting Facility (WTF). Plant characteristics studied included foliar cation content, stomatal resistance, and rate of foliar decomposition. Eleven bogs similar in plant community structure and interstitial water chemistry were used as study sites. Treatment sites were located immediately adjacent to the WTF antenna or its grounds, and experienced EM field intensities at least two orders of magnitude greater than control sites. Intermediate sites were located so as to have EM

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intensities between those of the treatment and control sites. Data were collected at the study sites over the period 1983-1987. Prior to 1986, the WTF antenna was periodically energized at less than full amperage. Since then, operation of the WTF has been essentially continuous and at full amperage.

Examination for possible effects was accomplished using a nested analysis of variance with replicate bogs within EM groups (antenna, ground, intermediate, and control). Multiple regression and canonical correlation were employed to account for the variance in plant characteristics using measured environmental and EM values. Researchers found relatively few significant differences between sites in the examined plant characteristics. Those findings that were significant showed no consistent pattern, and in several cases significant findings were not supported upon further statistical analysis. The investigators concluded that the EM fields produced by an intermittently energized, or a fully operational, transmitting facility had no measurable effect on peatland plant species.

FOREWORD

The wetland studies constitute one of several projects in the ELF Ecological Monitoring Program. The purpose of the Program is to examine for possible electromagnetic effects to resident biota from the operation of the U.S. Navy's Extremely Low Frequency (ELF) Communications System. IIT Research Institute (IITRI), a not-for-profit organization, has been contracted by the Space and Naval Warfare Systems Command (SPAWAR) to provide engineering support and to manage the Program. The wetland studies were conducted under subcontract arrangements between IITRI and the University of Wisconsin-Milwaukee.

These studies were selected for funding by IITRI after a technical and cost review of an unsolicited proposal received during late 1982. Plant data were collected from 1983 through 1987. During 1988, the researchers completed their analytical efforts and prepared this final report.

This report documents the results and conclusions based on data collected over the term of the study. A draft manuscript of the text was reviewed by several peers with experience in such areas as wetland ecology, plant physiology, statistics, and electromagnetics. The authors considered and addressed peer critiques prior to providing this report to IITRI for publication. IITRI repaginated the report beginning at page 191; this was necessary because the authors inadvertently included a duplicate of one page. Otherwise the report is presented here without further change or editing by IITRI or SPAWAR.

Respectfully submitted,
IIT RESEARCH INSTITUTE

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WETLAND STUDIES

FINAL REPORT

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FINAL REPORT

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This work was funded by the Space and Naval Warfare Systems Command, Submarine Communications Project, under Contract Numbers N00039-81-C-0357, N00039-84-C-0070, and N00039-88-C-0065, to IIT Research Institute (IITRI).

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ABSTRACT

This report summarizes five years of field studies (1983-1987) designed to examine potential extremely low frequency (ELF) electromagnetic field effects on peatland ecosystems in northern Wisconsin. ELF electromagnetic fields did not influence decomposition of standardized cellulose strips nor Ledum groenlandicum foliar tissue. No consistent electromagnetic effects were detected in the foliar nutrient concentration of the dominant bog plants. Although statistical analyses provided conflicting results, ELF electromagnetic fields did not appear to have any influence on Ledum groenlandicum leaf stomatal resistance. We conclude from these studies that ELF electromagnetic fields generated by the Navy's Wisconsin Transmitter Facility had no measurable effect on bog plant species nor bog ecological processes.

SUMMARY

This report summarizes the results and activities associated with the wetland studies portion of the ELF Communication System's Ecological Monitoring Program. In these studies we examined possible effects of long term exposure to ELF electromagnetic fields on biological and ecological processes occurring within bogs in the vicinity of the Wisconsin Transmitter Facility (WTF). Our studies focused on foliar nutrient concentrations of selected bog plants, decomposition of organic material, and stomatal resistance of ericaceous shrub leaves. These are variables that can influence the structure and function of these systems.

Field studies, in the vicinity of the WTF, were conducted from 1983 to 1987. Most major study protocols were established by 1985. Eleven bogs, similar in plant community structure and interstitial water chemistry, were selected along the electromagnetic field gradient around the WTF. All environmental, electromagnetic field, and biological measurements were made in six plots located along a transect in each bog. Environmental parameters were measured and samples collected monthly during the growing season. ELF electromagnetic fields were measured only once each growing season and assumed to be relatively constant throughout the remainder of the year. Biological test variables were sampled at appropriate time intervals in accordance with the sampling protocol established for each one.

We designated four electromagnetic treatments in our experimental design (ANTENNA, INTERMEDIATE, GROUND, and BACKGROUND). Each of the treatments represented a unique

combination of the electric field in air, the electric field in earth, and the magnetic field generated by the WTF. These data were summarized by Principal Components Analysis and the resulting Principal Components used for additional statistical analysis.

The experimental design was a nested analysis of variance model with replicate bogs within each electromagnetic treatment group. Multiple regression and its' multivariate counterpart (canonical correlation) were employed to account for the variance in biological variables using environmnetal and electromagnetic field measurements. Each sampling period and each variable was analyzed independently.

Stomatal resistance was measured on Ledum groenlandicum leaves twice in 1985 and twice in 1986. Nested ANOVA's and multiple regression models provided conflicting results concerning the influence of the ELF electromagnetic fields. Only one statistically significant electromagnetic treatment effect was found among the four measurement periods. However, the multiple regression model for this period (July 1987) only accounted for 29% of the variation present in stomatal resistance and no electromagnetic variable was selected for inclusion in the model. Although electromagnetic intensities were included in two of the other multiple regression models for other measurement periods, the results were contradictory. In one model the ELF electromagnetic variable had a negative slope while in the other it had a positive slope. Thus ELF electromagnetic fields appear to have no influence on leaf stomatal resistance.

ELF electromagnetic fields did not influence decomposition of organic matter placed in the bogs. Cellulose wood pulp and *Ledum groenlandicum* leaves were used as material for the decomposition studies. No significant treatment effects were detected in the nested ANOVA's for the cellulose experiments. However, the 1987 *Ledum groenlandicum* experiment revealed significant treatment effects in the ANOVA model. However, associated bog surface phenomena appeared to influence decomposition rates. Therefore, we categorized moss cover over litter bags into four groups. We found more litter bags covered by moss (62%) in the ANTENNA sites than in the other three types of sites (25-35%). Multiple regression models generally accounted for 30-35% of the variation in weight loss. Although ELF electromagnetic intensities were selected as variables by the stepwise regression procedure, there were no consistent differences among bogs grouped as electromagnetic treatment types.

Foliar tissue samples from several bog plant species were collected during each growing season to determine if any differences in nutrient concentration could be assigned to ELF electromagnetic field exposure. Only five significant treatment effects were detected in 79 separate analyses - a frequency of occurrence no better than expected by chance alone. In addition, neither multiple regression nor canonical correlation models demonstrated that ELF electromagnetic fields accounted for a substantial percentage of variation in foliar nutrient concentrations.

No consistent electromagnetic effects were detectable in our

experiments. Although occasional NESTED ANOVAS showed statistically significant treatment effects, the results of supplemental data analysis did not substantiate the rejection of the null hypothesis. More importantly, there were no measurable, long lasting treatment effects. Based on this evidence, we cannot attribute any biological significance to the results. Therefore we conclude that ELF electromagnetic fields generated by the WTF have no measurable effects on the plant species or the ecological processes that we studied in the bogs.

CHAPTER I

INTRODUCTION

This report summarizes a five year (1983-1987) field study of eleven bogs in northwestern Wisconsin exposed to ELF electromagnetic fields. Bogs are one type of wetland abundant in the vicinity of the Wisconsin Transmitter Facility (WTF). They have been shown to be sensitive to changes in hydrology, nutrient input,and physical disturbance (Heinselman 1970). However, despite their sensitivity to disturbance, they have not been previously studied in electromagnetic (EM) related research. Our objective was to determine whether long-term exposure to low intensity, ELF-EM fields generated by the WTF significantly influences selected biological processes and aspects of ecosystem processes.

Some evidence suggests that the cell membrane could be a site influenced directly by high intensity electromagnetic fields (Miller et al. 1980, 1983, Inoue et al. 1985). ELF-EM fields are effectively transmitted through water and soil. Thus, in water saturated soils typical of wetlands, the most likely site of interaction would be the soil-root interface (NRC 1977). To study potential ELF electromagnetic effects, we chose variables that could be affected if membrane function were altered and, that if changed significantly, might also influence bog ecosystem processes. We selected litter decomposition, nutrient concentration in foliar tissue of the dominant plant species, stomatal resistance, and nitrogen fixation as processes for study (Table 1.1). We selected species representative of the three major plant community strata: a tree (<u>Picea</u> <u>mariana</u>),

Table 1.1. A list of biological variables studied for responsiveness to ELF electromagnetic fields in a study of wetlands surrounding the WTF, 1983-1987 and the study subject selected for examination.

STOMATAL RESISTANCE

(LEDUM GROENLANDICUM)

DECOMPOSITION

(CELLULOSE)
(LEDUM GROENLANDICUM)

FOLIAR NUTRIENT CONTENT

(LEDUM GROENLANDICUM)
(CHAMAEDAPHNE CALYCULATA)
(PICEA MARIANA)
(SMILACINA TRIFOLIA)

NITROGEN FIXATION

(MOSSES)
(PEAT SUBSTRATE)

shrubs (Ledum groenlandicum and Chamaedaphne calyculata), and a herbaceous species (Smilicina trifoliata).

The rate of peat formation and patterns of plant community development in bogs appears strongly related to dynamics of water movement and biogeochemical cycling (Heinselman 1970, Glaser etal. 1981). Changes in patterns of nutrient cycling, water movement, and vegetative interactions can alter both ecosystem structure and function. In bogs, ecosystem level changes typically take place over a period of years. However, changes in foliar nutrient concentration and rates of decomposition, nitrogen fixation, and diffusive resistance can be used as indicators of potential ecosystem level changes.

This report is organized into five sections. First, there is a chronology of field studies, including modifications and changes made during the five year study. Second, there is a description of the experimental design, including site selection procedures and the rationale for using various statistical tests. Information on EM criteria for site selection, protocols for EM measurements, EM intensities at study sites, and operational characteristics of the WTF are given in the Appendicies. This information was provided by IITRI for our use. Additional information on the ELF Communication System, and the nature of the ELF-EM fields produced by it, can be found in Haradem et al. (1988). Third, we examine the methods used to construct the data base for environmental and biological variables. Fourth, we present the analysis of results and show how they relate to our objectives and hypotheses. Finally, we conclude with a discussion of the statistical and biological importance of our results.

CHAPTER II

EXPERIMENTAL DESIGN

HYPOTHESES AND RATIONALE

The Navy's ELF Communications System uses ELF (generally 76 Hz) EM fields to transmit information over long distances to submerged submarines. Bogs are present near the Communications System and are particularly abundant in areas adjacent to the WTF. It was not known if EM field intensities produced by the Communications System affect plants or plant communities. This study was designed to determine whether exposure to the low intensity EM fields generated by an operational WTF could affect important wetland processes.

EM measurements made at the beginning of the study, indicated that 76 Hz fields were detectable at all potential study sites. In addition, the WTF had been operating for many years before we began our research. Therefore, we could not use a design involving true control sites. These realities supported our earlier decision to use a gradient analysis approach in which study sites were located along a 76 Hz EM gradient.

In order to ensure significant ELF EM differences between study sites, criteria had been established by IITRI (Appendix A). These criteria required that 76 Hz ELF-EM field intensities at "test" sites be at least one order of magnitude greater than those present at "control" sites and at least one order of magnitude greater than 60 Hz EM field intensities from electric power sources.

The four sampling areas (treatments) along the EM gradient: BACKGROUND, INTERMEDIATE, ANTENNA, and GROUND correspond to

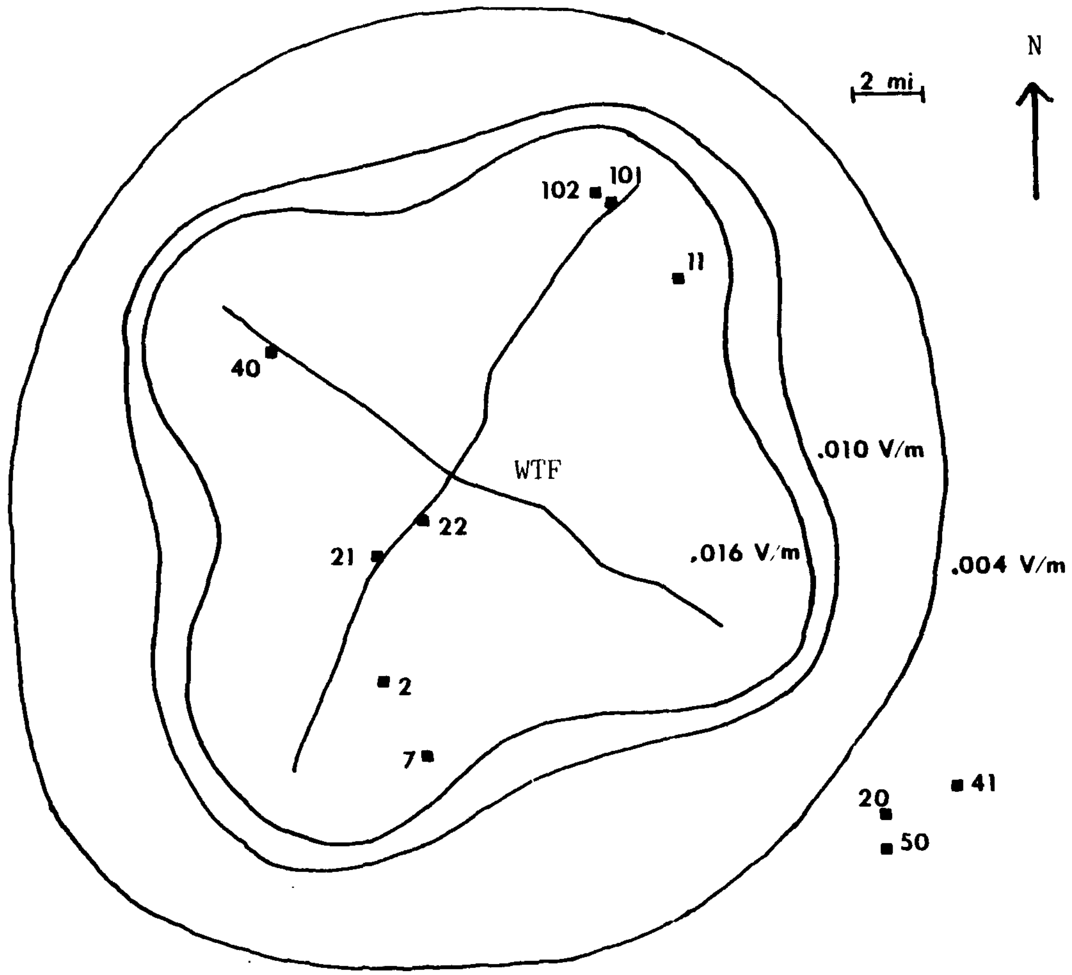


Figure 2.1. Location of study sites relative to the electric field produced in the earth by the Wisconsin Test Facility (WTF). Field intensity is presently 0.17 V/m under the antenna.

proximity to the aerial and buried portions of the Communications System (Figure 2.1). Each treatment consisted of two or three replicate bogs chosen for their similarity in species composition and environmental characteristics. Six replicate plots were identified within each site. Measurements of the dependent and independent variables were made in each plot.

Analysis of variance models were used to determine if there was an ELF treatment effect for any of the dependent variables studied. A nested design was used to separate variation inherent among replicate bogs from variation assignable to the ELF treatment categories. We measured a number of environmental variables and IITRI measured three ELF-EM fields (air, earth, and magnetic) in each of the plots. Plot means of the dependent variables were then related to the independent environmental and ELF-EM field variables by multiple regression. The proportion of variance explained in the dependent variable by the independent variables (especially the ELF-EM variables) could then be examined.

SITE SELECTION

An initial wetland screening was done in 1983 to find sites with similiar plant communities and environmental characteristics along the gradient of ELF-EM field strength. Initially, we identified over 200 potential wetland sites using black and white infra-red and black and white panchromatic aerial photographs of the Chequamegon National Forest, low level aerial photography supplied by GTE, and by extensive field surveys. Our initial site selection criteria included:

1) commonness of the wetland community in the WTF area

2) constraints of the ELF (76 hz) and electrical transmission line (60hz) field strength criteria

3) distribution of potential sites within the framework of our experimental design

4) similarity of the plant communities and environmental variables among sites

5) accessibility of the site.

The ANTENNA group (Bog's 21,22,40) includes peatlands within 0.05 km of the antenna system. The INTERMEDIATE sites (Bog's 2,7,11) are located between the antenna arms and had lower (intermediate) field intensities than the ANTENNA sites. The BACKGROUND sites (Bog's 20, 41,50) were those that had field intensities two orders of magnitude lower than 76hz ANTENNA field intensities. The fourth group of sites (Bogs 101 and 102) were adjacent to the north GROUND terminal of the antenna. Unlike the other treatment types that consisted of three replicate sites, the GROUND type was restricted to two sites within one large peatland. This restriction was imposed by the slow rate of attenuation in 76hz fields from the ground portion of the antenna and limitations in the availability of sites at this and other ground terminals. Even so, all three 76hz field components (earth, air, and magnetic) differed by a factor of two between these two sites. Moreover, because the source of ELF-EM fields at the ground terminal was buried rather than aerial, the pattern of air, earth, and magnetic fields differed somewhat from the other treatment types (Appendix B).

We measured additional community attributes in 1983 and

monitored several water quality parameters in 1983 and 1984 before making our final selection of sites. An alternate BACKGROUND site (Bog 50) was chosen in 1984 because of extensive logging around Bog 19 which was originally chosen. We felt the logging disturbance had the potential to cause significant changes in bog water chemistry.

PLOT SELECTION

Within each site, a 70 X 15 metere plot was established with the long axis parallel to the nearest antenna arm or ground terminal. The starting position was chosen without bias. Within the plot, six shallow groundwater wells (10 meters apart) were placed in the peat substrate. Samples were collected and measurements made from and adjacent to these wells (Fig. 2.2). In 1984 and 1985, plank boardwalks were put in place along trails leading to the sampling sites to minimize human disturbances.

Because of differences in the tree density data (Appendix C), we decided to relocate the sampling plots and transect in Bog 21. In 1984, we established a plot in a portion of the bog which had a treed density similar to that of the other sites and which also met our previously established water quality criteria. In 1984, we also established a new transect 5-10 meters parallel to the original transectand restablished the plots and sampling wells there. The initial field reconnaissance disturbed the sites to the extent that we believed additional sampling in the same area over a five-year period would cause serious deterioration of the study area. In 1985, planks were placed around each well to protect site integrity and minimize disturbance.These measures

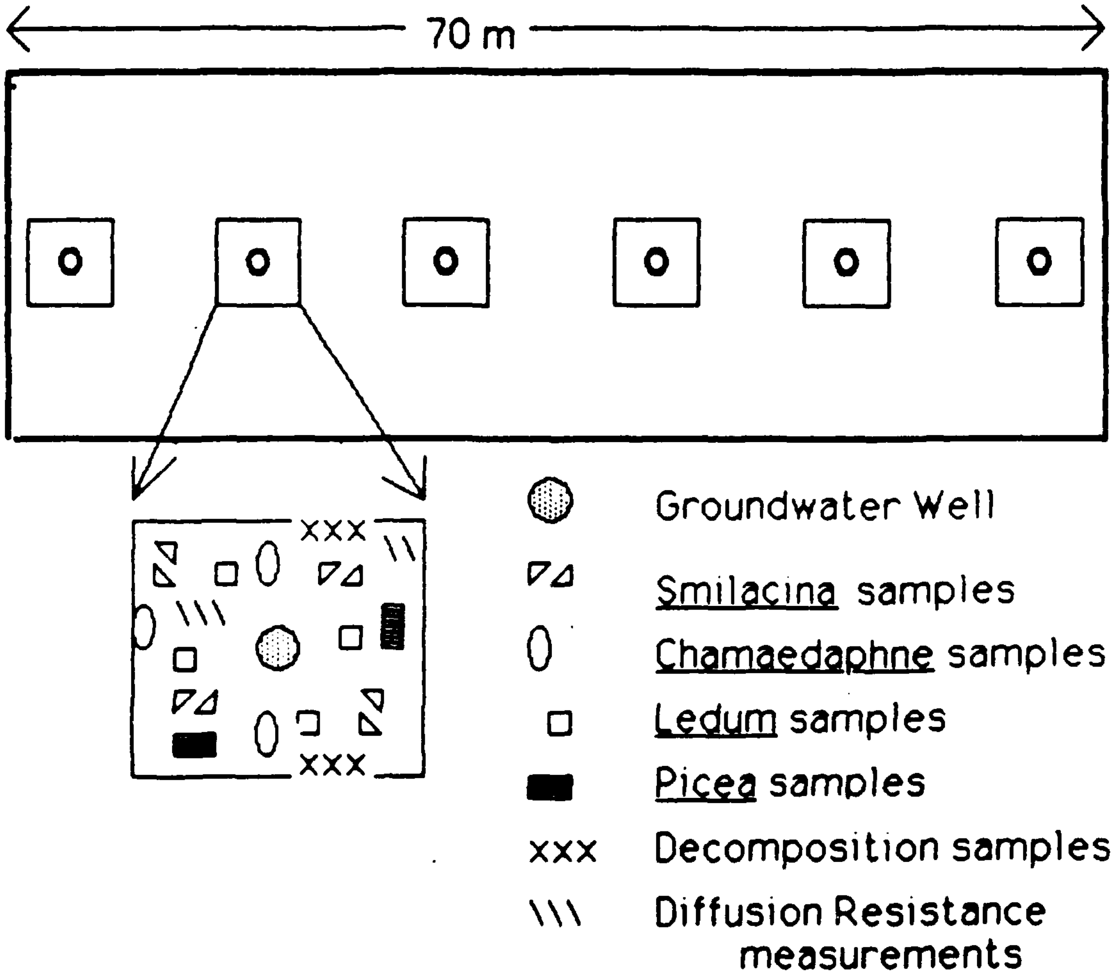


Figure 2.2 Diagram of transect design. Decomposition samples, diffusion resistance measurements, and leaf samples were collected within a plot around each well. Symbols shown do not reflect relative number of samples collected.

proved successful in preventing major damage to the plots without altering surface water flow patterns.

PROJECT CHRONOLOGY

Field studies were conducted from 1983 to 1987. Table 2.1 summarizes each of the major work elements in our study and provides information on major changes in methodology, sampling protocol, or shifts in emphasis over time. For example, in 1983 we began preliminary measurements of environmental variables. We assessed the capabilities of our instrumentation and examined seasonal variability in interstitial bog water chemistry. In 1984, we added redox, depth to water table, and color measurements. However, accurate redox potential measurements could not be made and therefore were discontinued in 1985. Permanent PVC wells were set in place in 1984 and boardwalks in 1985. Thereafter, we had an acceptable protocol for measuring environmental variables that we used through 1987. Similar changes in other important study elements are summarized in Table 2.1.

Major activities during 1983 and 1984 consisted of selecting sites, validating the assumptions made in the initial study plan, characterizing the sites, refining the methodology needed to measure the various biological and environmental variables, and assessing the adequacy of our statistical techniques. The major work elements were established by 1985. However, at the end of the 1985 field season, we decided to discontinue the nitrogen fixation studies (see Nitrogen Fixation section under Results).

Environmental data were collected monthly from May to September (during the frost-free season). ELF-EM fields were

Table 2.1. Chronology of field study tasks, 1983-1987.

Environmental Variable

1983 (Preliminary sampling, assess seasonal variability)

Measure 1. Temperature 2. pH 3. conductivity

1984 (Preliminary sampling, add permanent wells)

Add measurements of 4. redox 5. color 6. water depth

1985 (Add boardwalks around wells, drop redox measurements)

1986 (Continue routine monthly sampling)

1987 (Continue routine monthly sampling)

Site Selection

1983 (Selection of study sites, measure environmental, biological and ELF-EM properties of sites)

1984 (Replace site and change plot locations, subdivide plots into six sub-plots))

1985 (Add boardwalks to protect site integrity)

1986 (Routine check on site integrity)

1987 (Routine check on site integrity)

ELF Measurements

1983 (Preliminary measurements, intermittent antenna operation)

1984 (Low intensity intermittent antenna operation)

1985 (Low intensity intermittent antenna operation, switchover)

1986 (Fully operational antenna, only 76Hz fields measured, change in ELF-Em field strengths at certain sites)

1987 (Fully operational antenna)

Nitrogen Fixation

1983 (Collection of alder seed)

1984 (Growth and innoculation of alder in nutrient culture)

1985 (Change to measuring moss and peat)

1986 (Drop work element)

Table 2.1 (Continued)
Stomatal Resistance

1983 (Development of sampling protocol)

1984 (Preliminary measurements)

1985 (Preliminary measurements to assess variability, initial sampling with leatherleaf and labrador tea)

1986 (Regular measurements with Labrador Tea)

1987 (Increase sample size, continue measurement of labrador tea)

Decomposition

1983 (Preliminary sampling with cellulose)

1984 (Continue use of cellulose , change length of incubation)

1985 (Change to use of natural plant material - Labrador Tea)

1986 (Continue with Labrador Tea, study placement of samples)

1987 (Increase sample size)

Foliar Nutrients

1983 (Preliminary sampling, investigate analytical techniques, analyze for calcium, potassium, magnesium, sample five species)

1984 (Increase sample size, sample spruce only once during season)

1985 (Add Labrador Tea, drop Carex and Eriophorum, increase sample size)

1986 (Sample Labrador Tea, leatherleaf, Smilicina, spruce)

1987 (Increase sample size but sample each species only once, analyze for phosphorus and manganese)

Statistics

1983 (Use anova and regression)

1984 (Use anova and multiple regression)

1985 (Use anova, multiple regression, and discriminant analysis)

1986 (Use anova, multiple regression, principal components, and other multivariate techniques, change to using SAS)

1987 (Use SAS and add canonical analysis)

measured once a year and assumed to remain constant over the course of each year. In 1986, stomatal resistance and decomposition studies were shifted to focus on the use of Labrador Tea (a native shrub) as the test organism. In addition, Labrador Tea was added to the species collected for foliar nutrient analysis. Throughout the study, each biological or ecological variable was measured several times each growing season. Each measuring period was analyzed independently for statistical significance.

The variability in the measurements of our dependent variables was assessed each year in an effort to improve the accuracy and precision of the measurements and also assess the adequacy of sample size in the experimental design. For example, we either increased the number of replicate samples per bog or improved our sampling protocol in an effort to reduce within-site variation. In 1987, we significantly increased the sample size of all the dependent variables. However, this forced us to reduce our sampling frequency for some of the study elements (Table 2.1).

Some of the changes we made in our field studies coincided with changes in the condition of the antenna (Appendix D). The Wisconsin transmitter had been operating in various modes from 1969 to 1984 and for sporadic periods. In 1985, new transmitter equipment was installed and the antenna was not in use for long perionds of time. During the last quarter of 1985, the WTF was returned to nearly continuous use with phased operation of the two antenna elements at full strength. This full-time operation continued during 1986 and 1987.

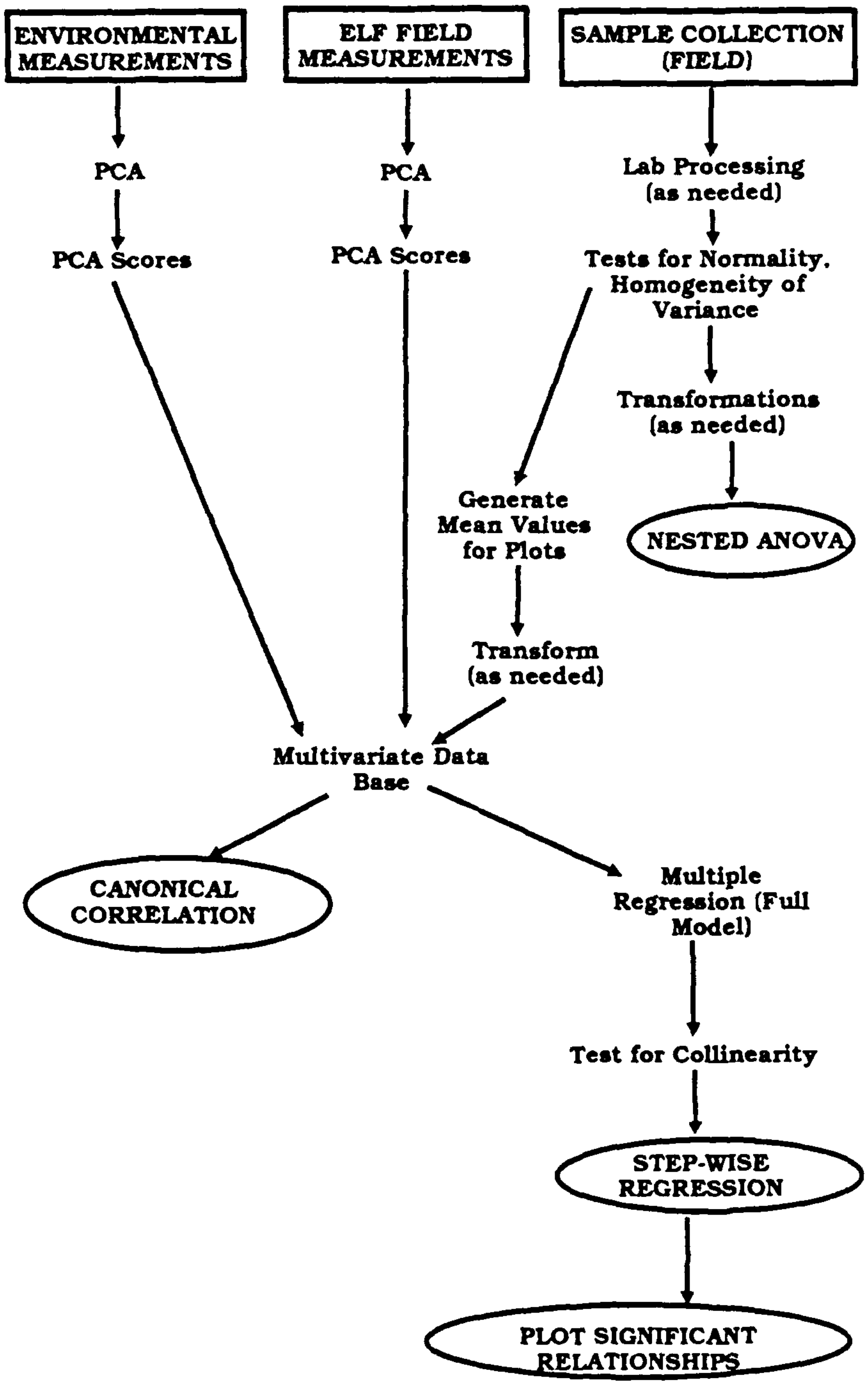
CHAPTER III

STATISTICAL ANALYSES

Statistical analyses of the data were chosen to address the following null hypothesis: that 76 Hz electromagnetic fields, as measured directly by IITRI personnel or as expresses as groupings of replicate bogs along the ELF field gradient, have no effect on selected ecosystem variables. Analysis of variance models were used to examine the treatment groups, and multiple regression models were employed to explain the variance in the biological variables, using environmental measurements and measured electromagnetic fields. The primary statistical references used were: Dillon and Goldstein (1984), Sokal and Rohlf (1981), and Zar (1987). A variety of computer programs were used over the course of the study; the results presented here were all completed using PC-SAS (SAS Institute, Inc. 1987). These are summarized in a flow chart showing the series of procedures used in data analysis (Fig. 3.1).

The selection process used in choosing the replicate bogs and the sample transect design was explained in the preceding section on experimental design. Sample size for each test variable was increased over the several-year course of the study to meet two criteria: 1) sample size should provide a reasonable certainty (80 % at best) of detecting a particular difference (20 % at best) among sample means at the 0.05 level of significance, and 2) sample size should permit expeditious collection and field and laboratory processing. We used power analysis (Zar 1987) to determine the appropriate sample sizes for the test variables.

Figure 3.1. Flow chart illustrating the steps taken in processing the biological and environmental samples and analysing the data. Rectangles signify raw data and ovals represent final analyses.



Each data set was examined to assure that the assumptions associated with the general linear model were met. The assumptions were: 1) the sample groups have equal variances and 2) the samples followed a normal distribution.

The computer program BIOM (Rohlf 1987) was used to test for normality and equality of variance in the data sets. The Sheffe' -Box log anova test was used to test for homogeneity of variance. Moment statistics (G1 and G2) and the Kolmogorov-Smirnov statistic were used to test for normality. In some cases, variables were transformed to meet the criteria of normality and homogeneity of variance before preceding with further analyses. When a transformation was required, the Box-Cox transformation was used to estimate lambda; this indicated which transformation (For instance, reciprocal or square root) would best meet the above criteria. This procedure was followed for every data set.

The experimental design, with ELF treatment groups (Background, Intermediate, Antenna, Ground) each comprised of replicate bogs, involved a nested analysis of variance model to test for significant treatment (ELF group) effects. Although we chose bogs that were biologically, structurally, and chemically similar, there was some variation among the sites. The nested design was used to separate variation inherent among replicate bogs from variation which could result from ELF treatment effects. In some cases, covariates, such as initial weight of decomposition samples or light or temperature measurements taken concurrently with measures of diffusion resistance, could be used to account for some of the variance. The model took the following

form:

$$Y_{ijkl} = u + a_i + B_{ij} + C_{ijk} + D(X_{ijkl} + e_{ijkl}$$

where Y = dependent variable (Biological variable), u = grand mean, a = ELF treatment effect (fixed), B = bog within treatment effect (random), C = plot within bog effect (random), D(X) = covariate effect, and e = error term. The appropriate F statistics were generated by dividing the group mean squares by the mean squares of the subgroup nested within it. When a significant ELF treatment effect was detected in the nested anova, we conducted unplanned multiple comparisons of means (GT2) (Sokal and Rohlf 1981).

The environmental data (collected from each plot simultaneously with the samples for the biological variables, and the electromagnetic field measurements (measured annually in each plot by IITRI personnel) were used to examine patterns in the test variables. Several environmental variables were correlated with one another; this was expected, because many are influenced by the same biogeochemical processes occurring in peat. Rather than deciding arbitrarily which variables to eliminate to avoid collinearity, we used principal components analysis (PCA) to generate new sets of uncorrelated variables (principal components) (Johnson 1978, Chatfield and Collins 1980). The environmental data set used for each analysis was chosen as representative of conditions appropriate for each set of biological samples. For example, for an analysis of plant nutrients from July, environmental data from May - June were subjected to PCA. Each component generated with PCA is a linear combination of the original variables; its' correlation with each

of the original variables is indicated by the loadings. Criteria for selecting the principal components for use in regression analysis included: 1) that the eigenvalue was greater than one and 2) there must be high loadings for a unique set of original variables (i.e. clear interpretation of the component). A new set of standardized scores (mean = 0 and variance = 1) was generated for each component; these corresponded to the 66 sample plots (11 bogs, 6 plots per bog. These components could then be used as independent variables foe multiple regression analysis. Besides permitting the use of all the environmental variables (instead of eliminating those that were collinear), PCA led to a reduction in the number of independent variables, thus simplifying the final model. The results of each principal components analysis are included in the discussion of each data set.

Significant correlations were also found among measurements of ELF electric fields in earth and air, as well as magnetic flux density (see the following section). When these data were subjected to PCA, only one principal component met the previously stated criteria for use (Table 3.1). Therefore, each multiple regression used only one electromagnetic component. The loadings on the earth, air, and magnetic field variables were roughly equal.

Multiple regression analyses were used to compare the mean values for biological variables associated with each plot (6 plots/bog) with relevant environmental and ELF measurements (for example, mean initial weight of decomposition samples or mean light levels measured with diffusion resistance, principal

Table 3.1. Results of PCA for ELF electromagnetic field data from 1984 - 1987. In each case, the first component was the only one to meet the criteria for use; loadings of each variable (log transformed earth, air, and magnetic fields) on the first component are shown.

Year	Principal Component	Eigenvalue	Proportion of Variance Explained	ELF Variable	Loading on 1st Component
1984	ELF84-1	2.860	0.953	log air	0.584
	ELF84-2	0.138	0.046	log earth	0.585
	ELF84-3	0.002	0.001	log mag	0.563
1985	ELF85-1	1.890	0.945	log earth	0.707
	ELF85-2	0.110	0.055	log mag	0.707
1986	ELF86-1	2.827	0.942	log air	0.585
	ELF86-2	0.165	0.055	log earth	0.586
	ELF86-3	0.007	0.002	log mag	0.560
1987	ELF87-1	2.821	0.940	log air	0.587
	ELF87-2	0.171	0.057	log earth	0.585
	ELF87-3	0.009	0.003	log mag	0.559

components generated from environmental data from the test wells, and the electromagnetic component). An initial analysis used a full model, with all possible independent variables. Diagnostic tests for collinearity included generation of eigenvalues and condition indices, tolerance values, and variance inflation factors (Dillon and Goldstein 1984). Following this, a stepwise regression was conducted; with PC-SAS, this is a modification of the forward stepwise procedure, in which the F statistics of all variables are examined to meet a minimum requirement for entry or persistence in the model after each step. The step-wise process ends when none of the independent variables outside the model meet the entry requirements. Thus, no possible significant independent variables are excluded. The final model for each test variable takes the form:

$$Y = a + B_1X_1 + B_2X_2 + \ldots + B_nX_n + e$$

where Y = dependent variable, a = intercept, X = independent variable, B = partial regression coefficient, and e = error term. The results include a t-test for each slope (H_o: B = O) and estimates of standardized regression coefficients (StB). These permit comparisons of the strengths of independent variables in the model. For each biological variable, the coefficient of determination (R^2) indicates the proportion of the total variance attributable to the model fit. The results presented are values for R^2 that are adjusted for the model degrees of freedom.

Analysis of the foliar nutrient data revealed numerous bivariate correlations between the specific foliar nutrients and the environmental variables. We used canonical correlation analysis (Dillon and Goldstein 1984) to simultaneously analyze

the relationship between each set of variables from the foliar nutrient analysis and the corresponding set of independent variables. In this study, one set (the environmental and ELF variables) is the predictor set of variables and the other set (foliar nutrient concentrations) is the set of criterion measures.

The approach in canonical analysis is to find two sets of linear combinations of variables (canonical components), one for each set of variables such that the correlation between the canonical components is maximized. Because the procedure maximizes the correlation between the two sets of variables, we are more interested in assessing their practical, multivariate relationship. The canonical loadings reflect the degree to which a variable is represented by a canonical component by calculating the correlation coefficient between the two. One can use the canonical loadings to determine the proportion of variance in either data set accounted for by the nth canonical component. Finally, the redundancy coefficient measures the amount of variance in the dependent variable set that is accounted for by the predictor variable set.

In evaluating the results from each experiment and for each biological variable (decomposition, diffusion resistance, and leaf nutrient constituents), we assessed the results of both the analysis of variance and multiple regression models, as well as graphic patterns. Each experiment was designed to stand alone; from the outset, we did not intend to look for year-to-year effects. However, we looked for significant treatment effects

that were seen consistently over months or years. We would attribute greater "biological significance" to repeatable results, rather than to a statistically significant result that occurred only once over the course of the study. We also recognize that, out of a number of similar analyses (for instance, all of the analyses of variance for foliar nutrients in a given year) some significant results are expected due to random chance. Significant ELF treatment results in both a regression analysis and an analysis of variance would be taken to indicate that, not only is the test variable correlated with ELF fields, but that this effect is regional and consistent across the groups of replicate bogs.

CHAPTER IV

PROCEDURES AND RESULTS

ENVIRONMENTAL VARIABLES

Although the replicate bogs were selected because they were structurally and chemically similar, subtle differences between them were expected. Environmental differences among bogs and among plots within each bog are attributable to such factors as hydrology, microtopography, and historical disturbance. We measured several characteristics of interstitial bog water, anticipating that these would represent conditions in the peat that were important to microbial decomposition processes and plant root functions.

Permanent groundwater wells, made from PVC pipe (6.4 cm ID, 50 cm in length, with slits cut into the lower 20 cm), were inserted in the peat in the hollows between hummocks within each plot. Between samples, each was initially capped with a foam plug. Beginning in 1986, the plugs were replaced with loose-fitting PVC caps. These served to prevent animals and debris from falling into the wells, but permitted air exchange and groundwater movement through the wells.

At each sample date, the depth to the water table was determined by measuring the distance from the top of the well to the standing water in the well and subtracting from this value the distance from the well top to the peat surface (measured outside the well to the substrate just below the living moss). The water in each well was pumped out, removing at least two well volumes, and the well was allowed to refill. In each well, we measured water temperature and pH by immersing the tips of an

automatic temperature compensating (ATC) probe and an Orion Ross-type pH electrode in the water. The pH probe was double-calibrated to pH 4 and 7 prior to each measurement. Reading from a Markson pH meter were recorded in the field.

In 1984, we measured redox potential using an Orion platinum electrode inserted in the peat to a depth of 8 cm. Simultaneously, a calomel reference electrode was immersed in the surface-saturated peat. Measurements (in mV) were standardized to pH 7 by subtracting 58 mV per pH unit below pH = 7. Obtaining reliable measurements of redox potential proved to be extremely time-consuming and data were so variable that they were not useful in explaining patterns in the biological variables. This test was eliminated after 1984.

Specific conductance was measured using a Beckman conductivity meter; the platinum electrode probe was immersed in the water in the well. Readings were corrected daily for the probe response from measurements of a standard KCl solution (0.1 N) and each measurement was standardized to 25° C (Wetzel and Likens 1979).

Water from each well was pumped into an individual plastic sample bottle and placed on ice in a cooler for transport to the field laboratory. Typically, 18 to 24 water samples were collected each day. At the end of each day, all samples were filtered through glass fiber filters (0.45u). One half of the filtrate (100 ml) from each sample was preserved with 2 ml concentrated HNO_3 for cation analysis. The remaining 100 ml sample was refrigerated. All water samples were returned to the

analytical lab at the University of Wisconsin Center for Great Lakes Studies within six days following collection. Color of each unpreserved sample was measured as spectrophotometric absorbance at 320 nm using glass distilled water as a reference (Glaser et al. 1981). This method is typically used to detect humic material, the dominant organic fraction in the groundwater of peatlands. In 1984, we also measured dissolved organic carbon (DOC) directly for these samples, using a Beckman Carbon Analyser. The correlation between color measurements and DOC showed this to be a direct relationship (DOC = 50 (Color) - 0.7, $r^2 = 0.78$, N = 209). Hence, DOC measurement was considered unnecessary. Dissolved Ca^{++}, Mg^{++}, and K^+ were measured for the preserved samples using atomic absorption spectrometry.

Patterns of Environmental Variables

The patterns for various environmental variables across sites for 1984 - 1987 are shown in Fig. 4.1 through 4.8. Tables of mean values for environmental data summarized by month and by bog can be found in the annual reports to IITRI from 1984 to 1987. Temperature, for instance, exhibited a uniform and regular pattern across sites and across years (Fig. 4.1). Groundwater temperatures in all sites increased through July and then declined in autumn. This trend was expected and reflects the seasonal patterns of air temperature.

The other variables examined were probably influenced by hydrologic features of each site. Depth to the groundwater table is an indirect measure of the peat saturation. The patterns we noted from 1984 through 1987 reflect the seasonal rainfall, heating and cooling. Differences were seen among the four years

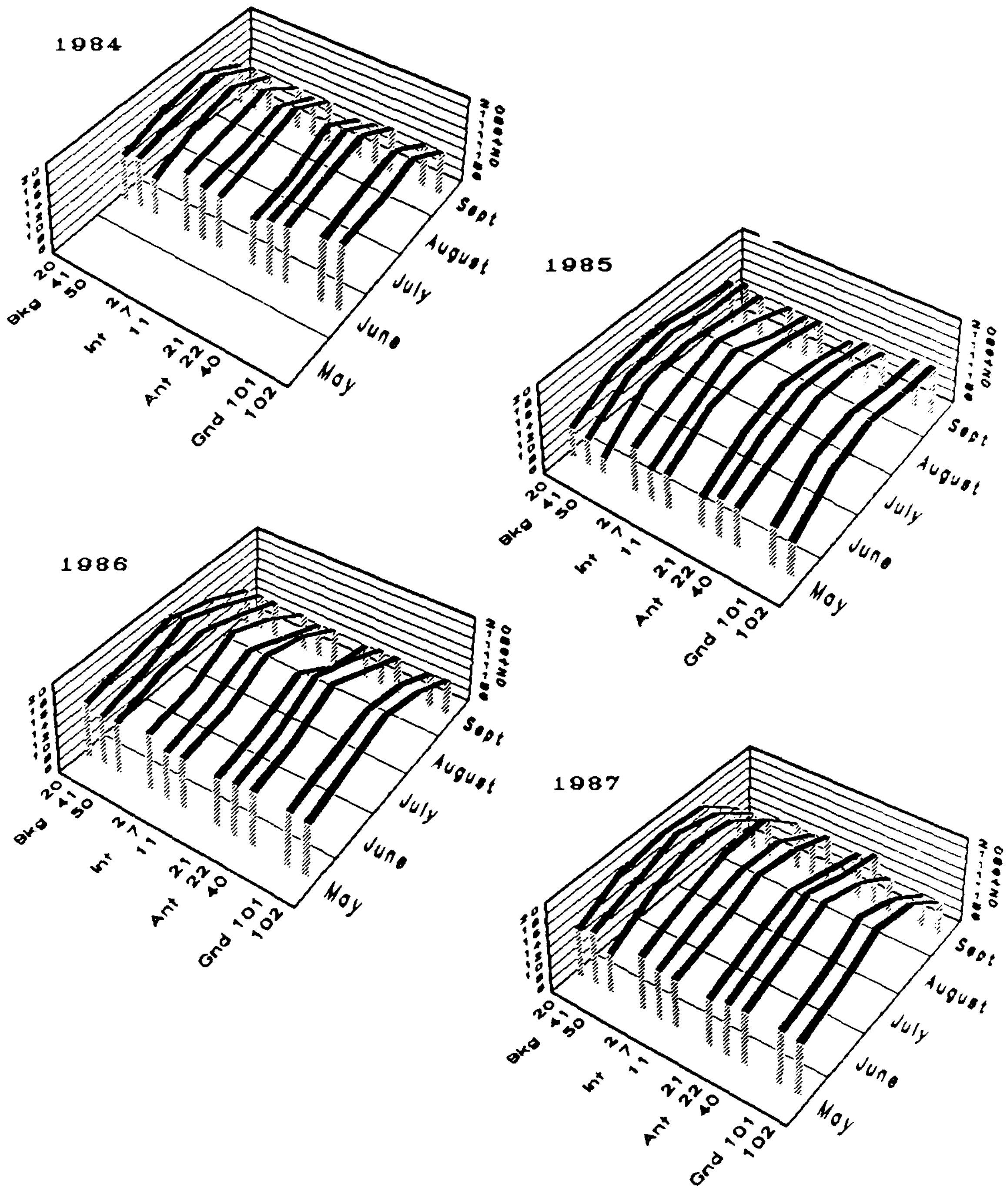


Figure 4.1. Mean values for temperature ($^{\circ}$ C) of interstitial water in each bog during each month of sampling in 1984 - 1987. The Y-axis ranges from 4° to 20° C.

of study (Fig. 4.2). Most years exhibited a decline in the water table (indicated by negative values) caused by dry, summer conditions. In July, 1984, measurements began when the water table was 4 - 14 cm below the surface and remained low through August, rising in response to rainfall in autumn. The 1985 field season was extremely wet; the water table was near the peat surface in all bogs throughout the year. In 1986, the bogs were very dry in June; the water tables were 1 - 10 cm below the surface during that month. However, the groundwater table did rise slowly during the fall. Bog water tables in 1987 reflected the regional drought. Rain in July raised the water tables in most sites, except in Ground sites 101 and 102. Those two bogs are sufficiently distant and north from the others that they may have been missed by localized rainstorms.

Because the plant communities were similar among sites and, among sites, the peat was relatively uniform in texture, color, and moss and wood content, differences in groundwater quality were probably caused by small differences in bog hydrology and in the degree of material exchange with the surrounding watershed. Explanation of the mechanisms involved in producing those differences was not the central purpose of this study. in discussing the patterns of environmental variables across sites and across years, we can only speculate on their causes.

Slight differences in pH were seen among sites, although all sites were acidic (Fig. 4.3). The range of values was only from pH 3.2 to 4.5. There were a few noticeable patterns that were consistent across years. Bogs 22, 101 and 102 were often found

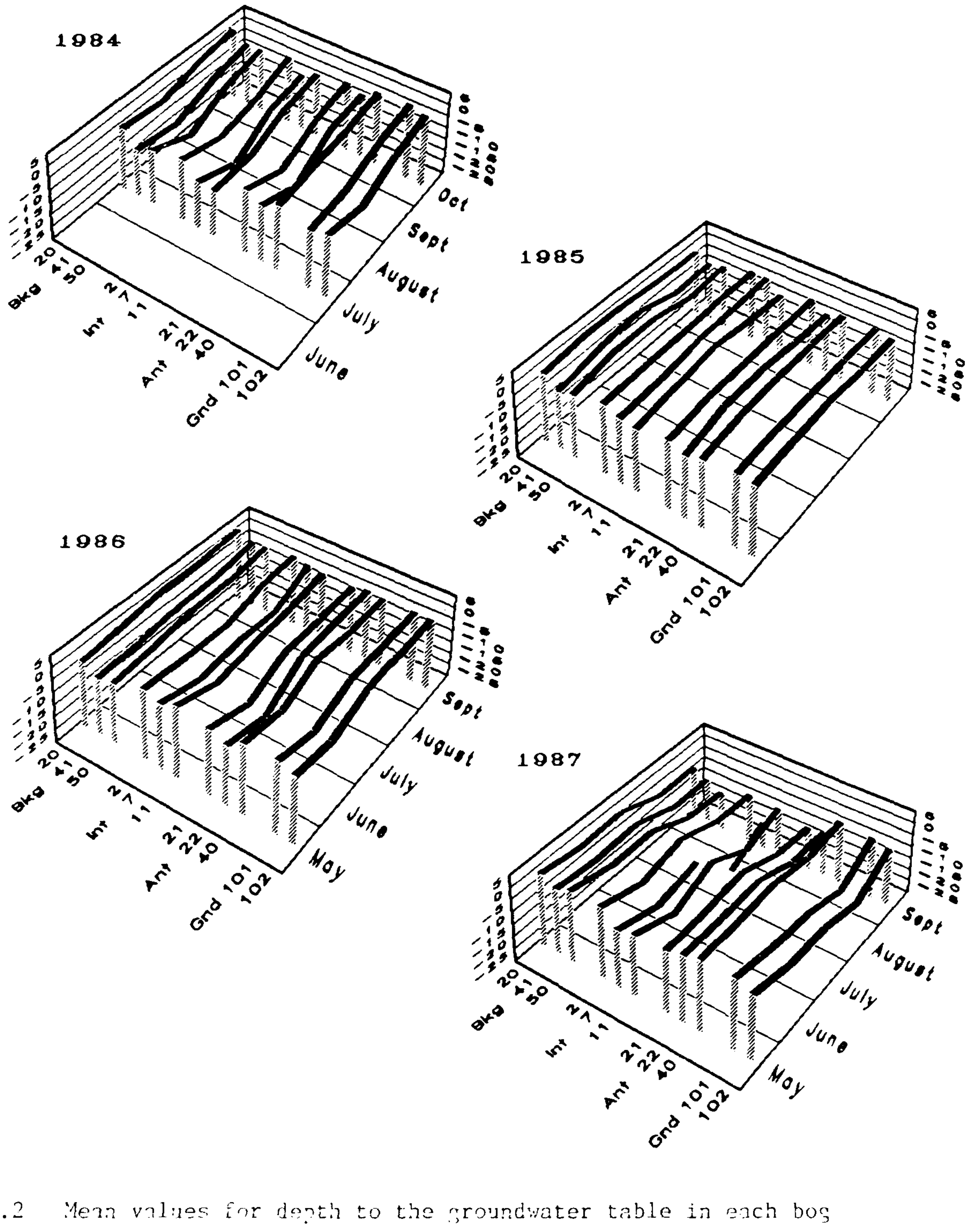


Figure 4.2 Mean values for depth to the groundwater table in each bog during each month of sampling, 1984 - 1987. The bog surface is represented by depth = 0 cm. Negative and positive values indicate the water table below and above the surface, respectively. The Y-axis ranges from -20 to 5 cm.

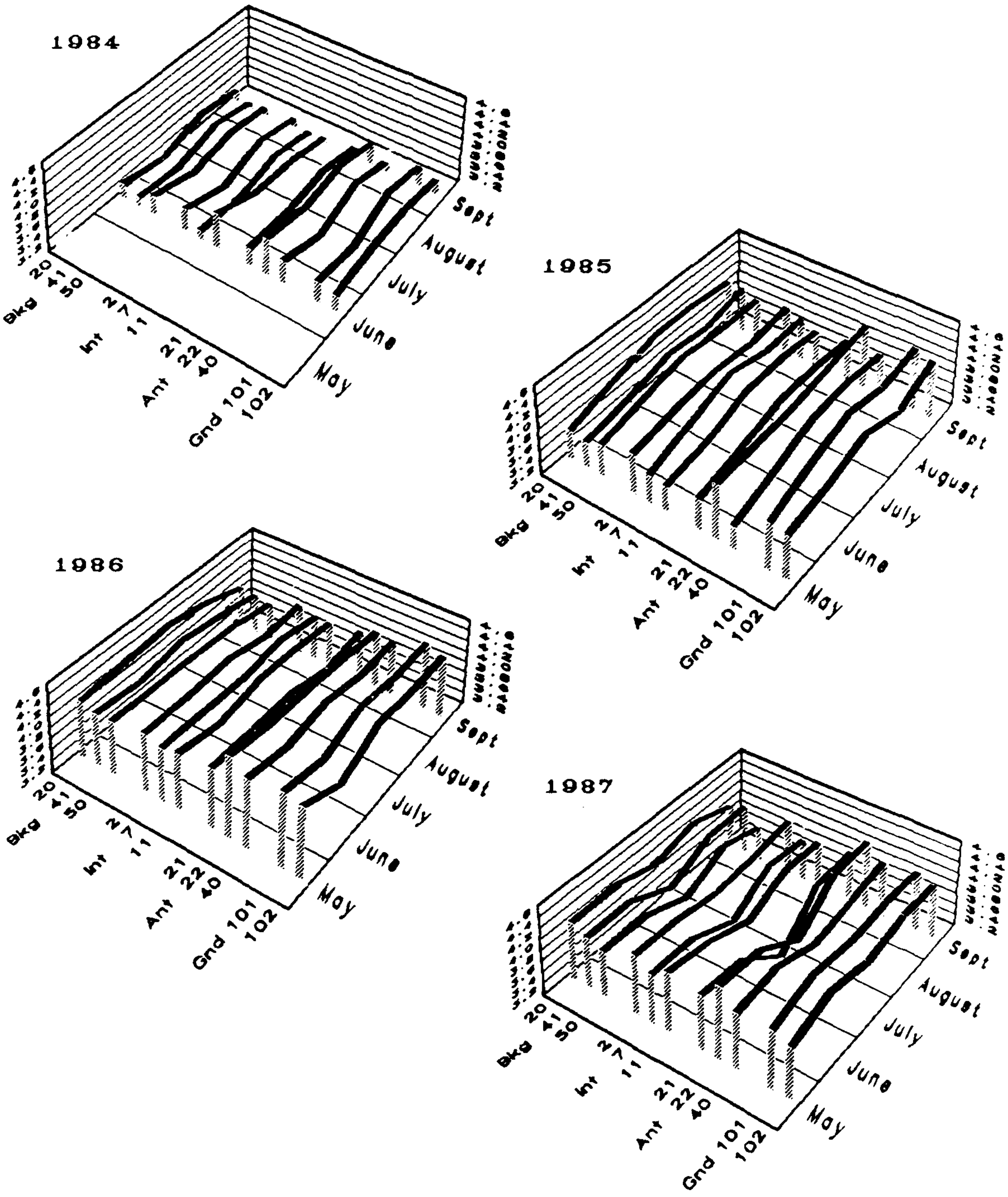


Figure 4.3. Mean values of pH in interstitial water in each month of sampling, 1984 - 1987. The Y-axis ranges from pH = 3.0 - 4.6.

to have a higher pH that the other sites, indicating slightly higher flushing rates or slightly greater inputs of buffering ions from the watershed. Bog 7 often exhibited a lower pH than the others. This site was somewhat drier than the rest, and more concentrated organic acids may have been responsible for the lower values. The pH levels in 1984 and 1985 were somewhat lower than those in 1986 - 1987. This difference may have resulted from higher concentrations of organic acids in the groundwater (see the patterns for color, Fig. 4.5); another explanation may be our change of measuring apparatus. In 1986, we began using a Ross-type electrode (we had previously used a standard epoxy-sealed field probe), that gave more stable readings in the poorly buffered groundwater of the peat. In all years, careful standardization was performed before each measurement, but we believe that, although within each year all measurements were standardized and comparable to one another, the 1986 - 1987 measurements reflect more accurate pH levels. These differences did not affect the statistical analyses, because we did not attempt year-to-year comparisons.

Specific conductance is a measure of the free ions in solutions. In poorly buffered, low ionic solutions, as in peat, conductance results from the organic acids present. Specific conductance range from 30 - 60 uS / cm. These are extremely low values for natural freshwater systems. Because organic acids make up the major conductive ions in these sites, specific conductance is inversely related to pH. The annual pattern in most sites was one of uniform values or slightly increasing values in fall (Fig. 4.4). Bogs 7 and 11 (two relatively dry

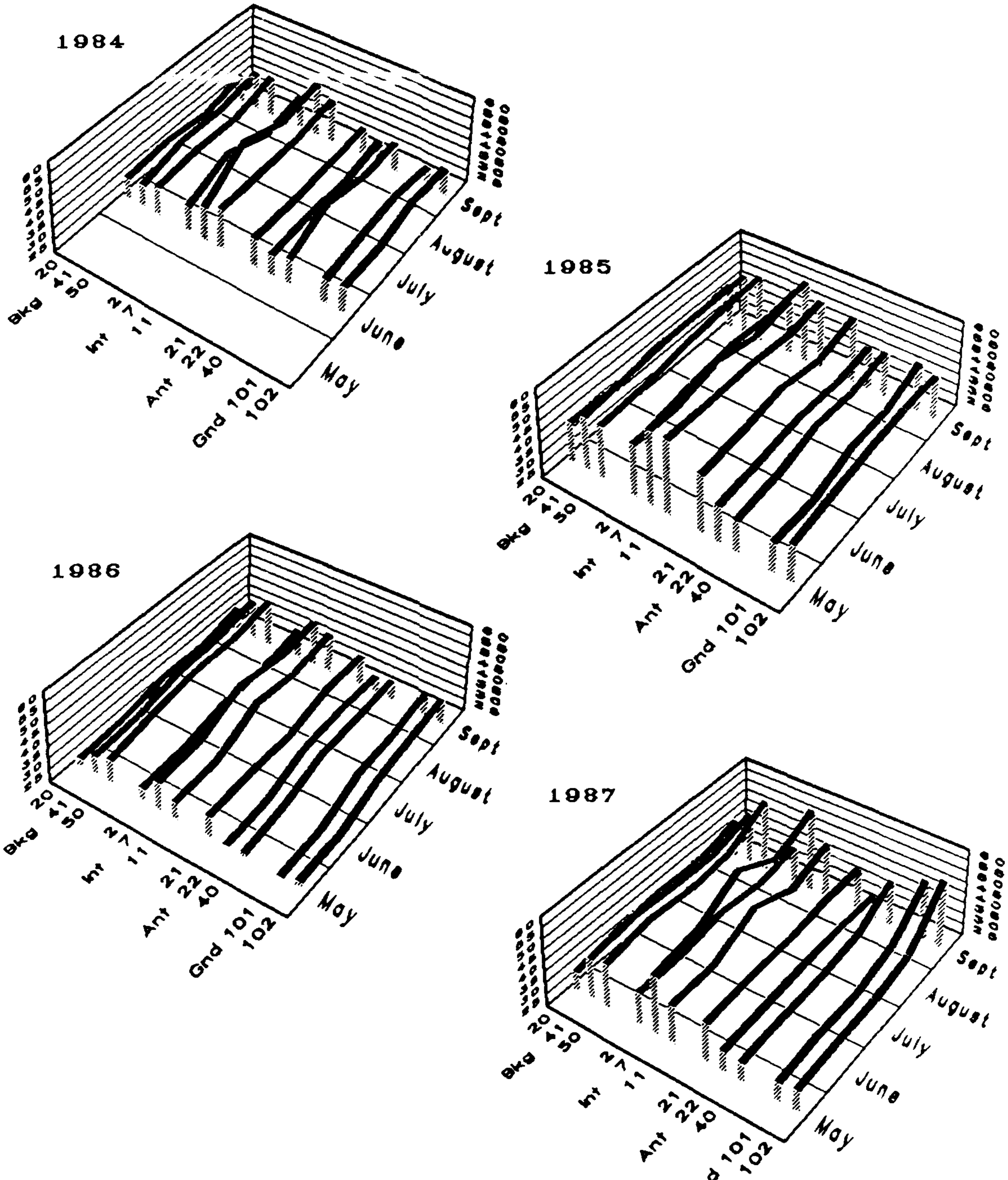


Figure 4.4. Mean values of specific conductance in interstitial water in each bog during each month of sampling, 1984 - 1987. The Y-axis ranges from 20 - 60 uS / cm.

sites) exhibited mid-summer peaks in conductance, probably caused by midsummer rain that flushed concentrated organic acids out of the partially dry peat.

Color is a measure of dissolved humic material in interstitial water; ground water from highly organic wetland substrate is typically colored yellow-brown. Color was almost lacking in all sites in July, 1986; rain during that month flooded all the sites and diluted the groundwater. In 1984, 1985 and 1987, water color was relatively constant through the field season (Fig. 4.5).

The dissolved cations in the interstitial peat water are influenced by plant uptake and release, peat decomposition, and flooding patterns that can either dilute dissolved material or flush ions from dry peat. Calcium, magnesium, and potassium were all present in very low concentrations in the interstitial water (Fig. 4.6 - 4.8). Several sites exhibited increased calcium and magnesium concentrations in the fall. Bogs 22 and 101 had calcium concentrations that were consistently higher than tne other sites, suggesting slightly higher allochthonous inputs. Dissolved potassium in the interstitial water exhibited a variable pattern among sites and years. In 1986, for instance, most sites showed elevated values in July, however, this pattern was not seen in other years.

Electromagnetic Field Variables

The 76 Hz electromagnetic (EM) fields generated by the Wisconsin Test Facility (WTF) were measured annually by IITRI personnel (see Appendix E for measurement protocol and Appendix B for measured EM values). The electromagnetic intensities in

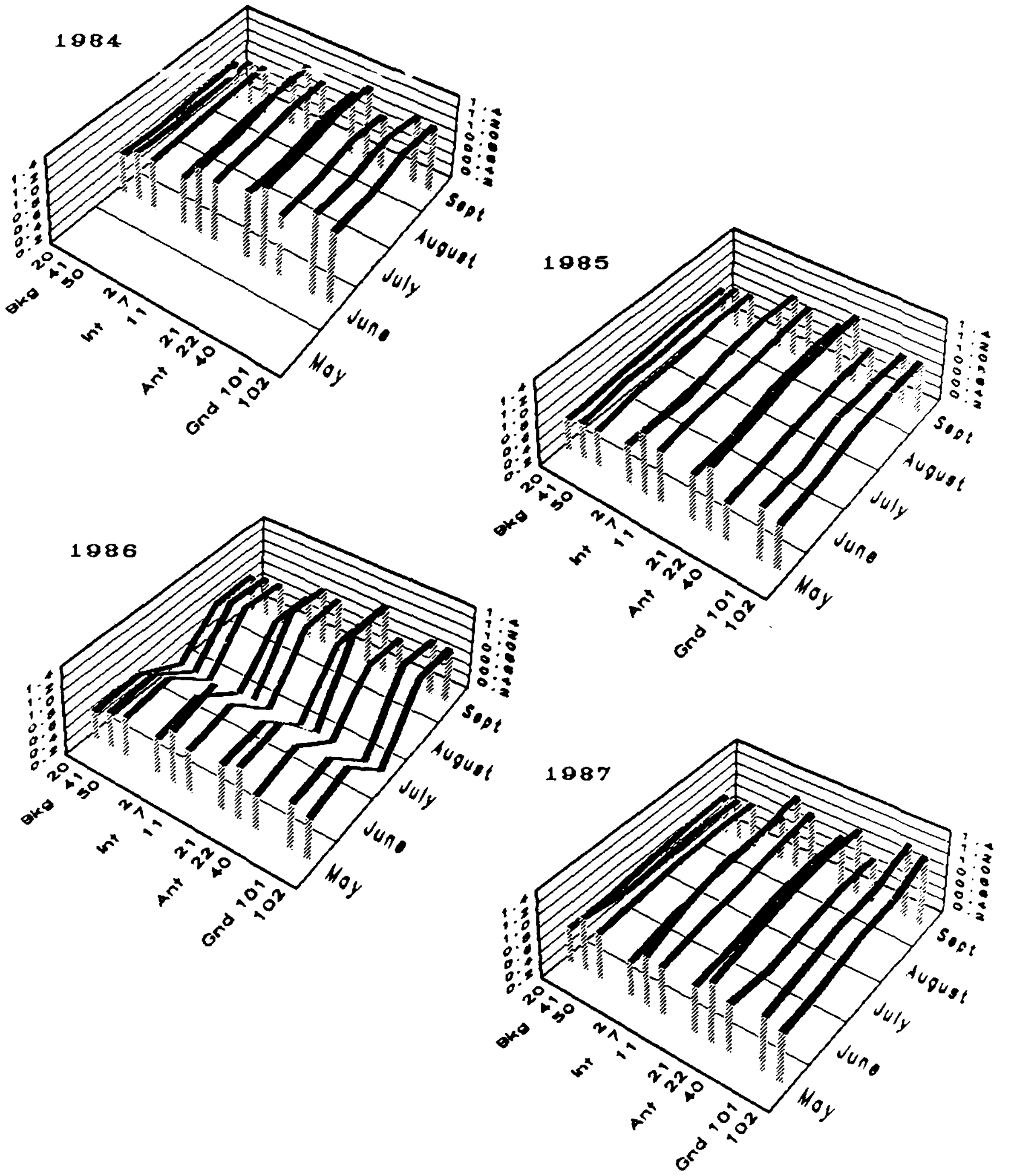


Figure 4.5. Mean values for interstitial water color (absorbance at 320 nm) in each bog during each month of sampling, 1984 - 1987. The Y-axis ranges from 0.0 - 1.4 abs. units.

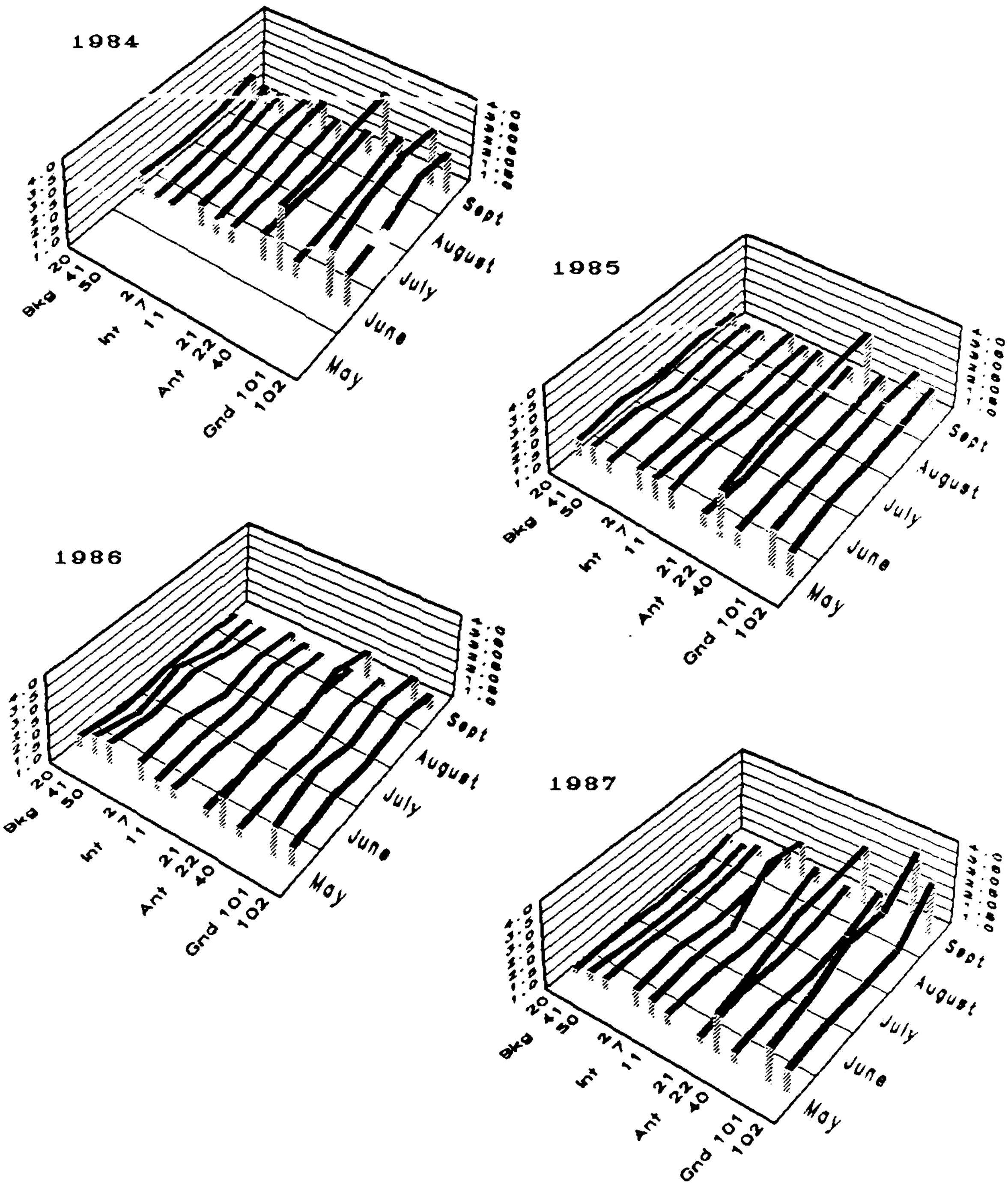


Figure 4.6. Mean values of interstitial concentrations of calcium in each month of sampling, 1984 - 1987. The Y-axis ranges from 0.5 - 4.0 ppm Ca^{++}.

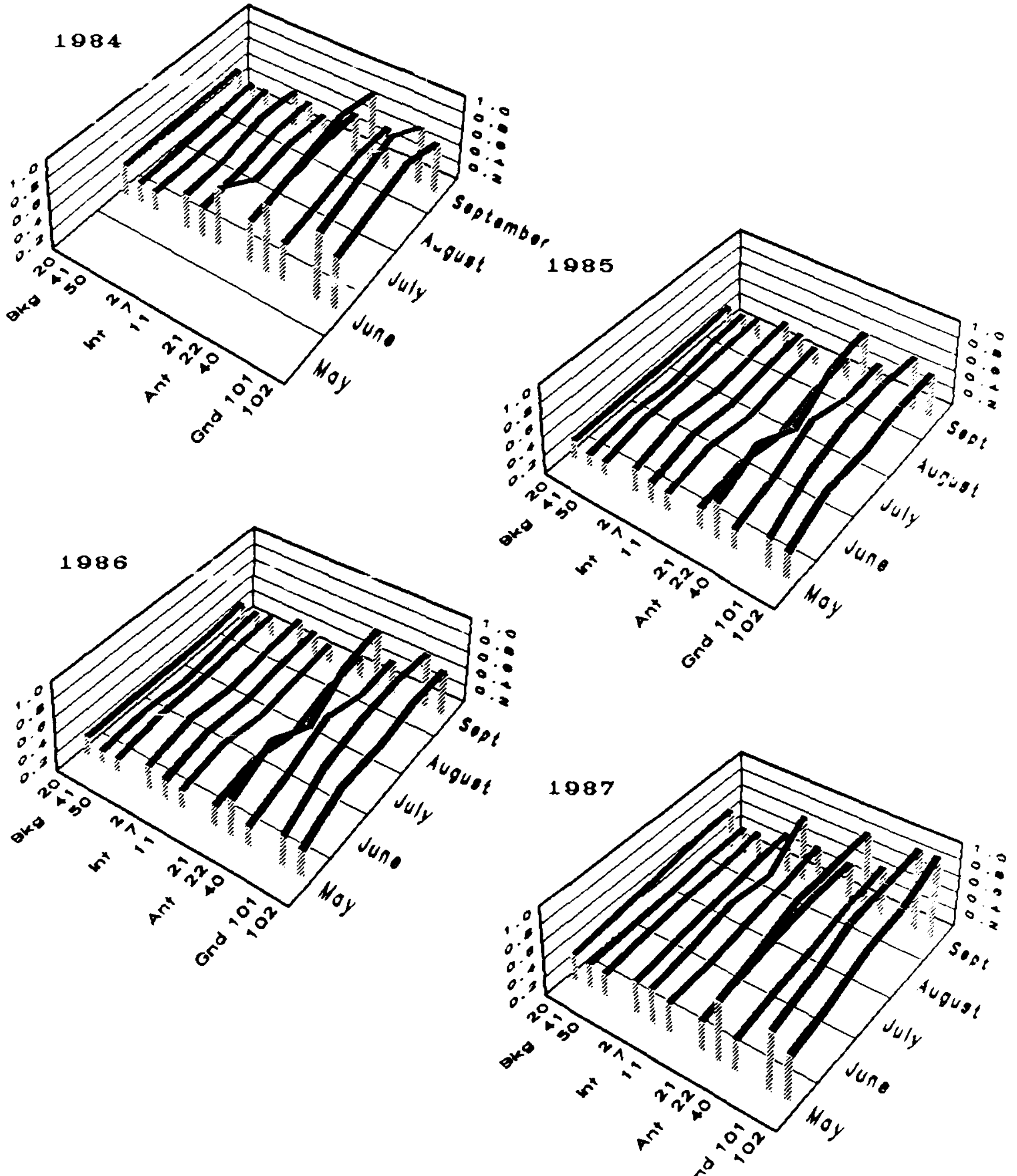


Figure 4.7. Mean values of interstitial concentrations of magnesium in each bog during each month of sampling, 1984 - 1987. The Y-axis ranges from 0.0 - 1.0 ppm Mg^{++}.

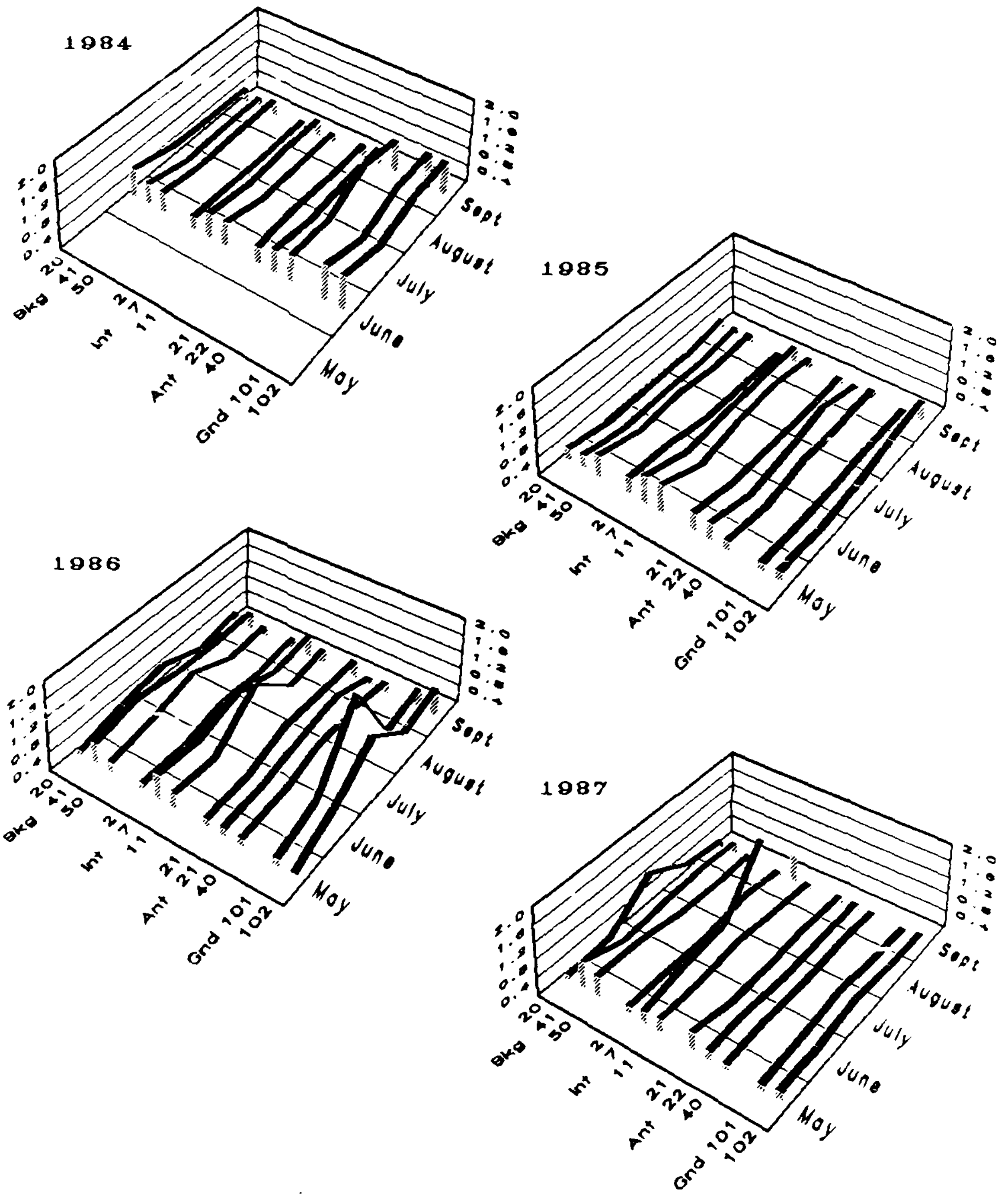


Figure 4.8. Mean values for interstitial concentrations of potassium in each bog during each month of sampling, 1984 - 1987. The Y-axis ranges from 0.0 - 2.0 ppm K^+.

Background, Intermediate, Antenna and Ground sites differed by several orders of magnitude (Fig. 4.9 - 4.11), however, the 76 Hz EM field intensities at each site were found to be relatively constant from year to year. Modifications to the WTF north ground terminal resulted in lower field intensities at sites 101 and 102 during 1986 and 1987 than had been previously measured. 1985 to 1986. Site 22 has a history of electric (but not magnetic) field fluctuations (IITRI 1987). Field strengths at this site in 1987 resembled those in 1985, while values in 1986 resembled those in 1984; we cannot offer and explanation for this.

The electromagnetic field data were log-transformed to meet the requirement of homogeneity of variance for the statistical analyses (Fig. 4.9 - 4.10). Electric fields in earth and air and magnetic fields were all induced by the current in the antenna and the ground terminal. As expected, both electric fields and the magnetic flux intensity were found to be highly correlated to one another (Table 4.1). For use as an independent variable in regression analyses, each set of 76 Hz EM field variables was subjected to a principal components analyses to avoid multicollinearity and to combine these variables. In every case, one of the three principal components met the criteria for use (eigenvalue > 1, large amount of variance explained) (Table 3.1).

In 1985, technical problems with IITRI equipment precluded a complete collection of air electric field measurements, and earth electic fields and magnetic fields were measured in alternating plots (3 measurements per bog) in all but the Antenna and Ground bogs. Estimates of the missing values for earth and magnetic field data were obtained by interpolation.

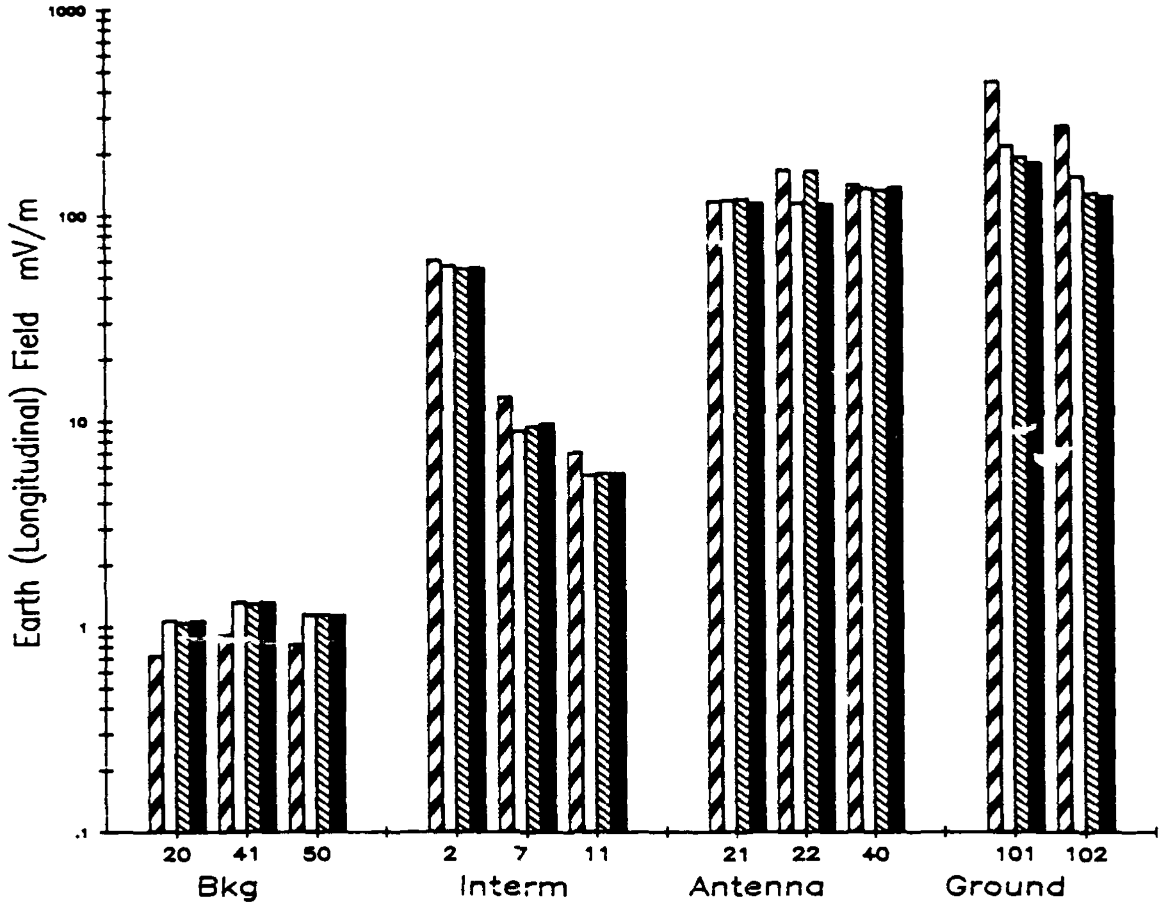


Figure 4.9. Mean electric field in earth (mV / m), as measured in each bog in 1984 (wide slash), 1985 (white), 1986 (narrow slash), and 1987 (black).

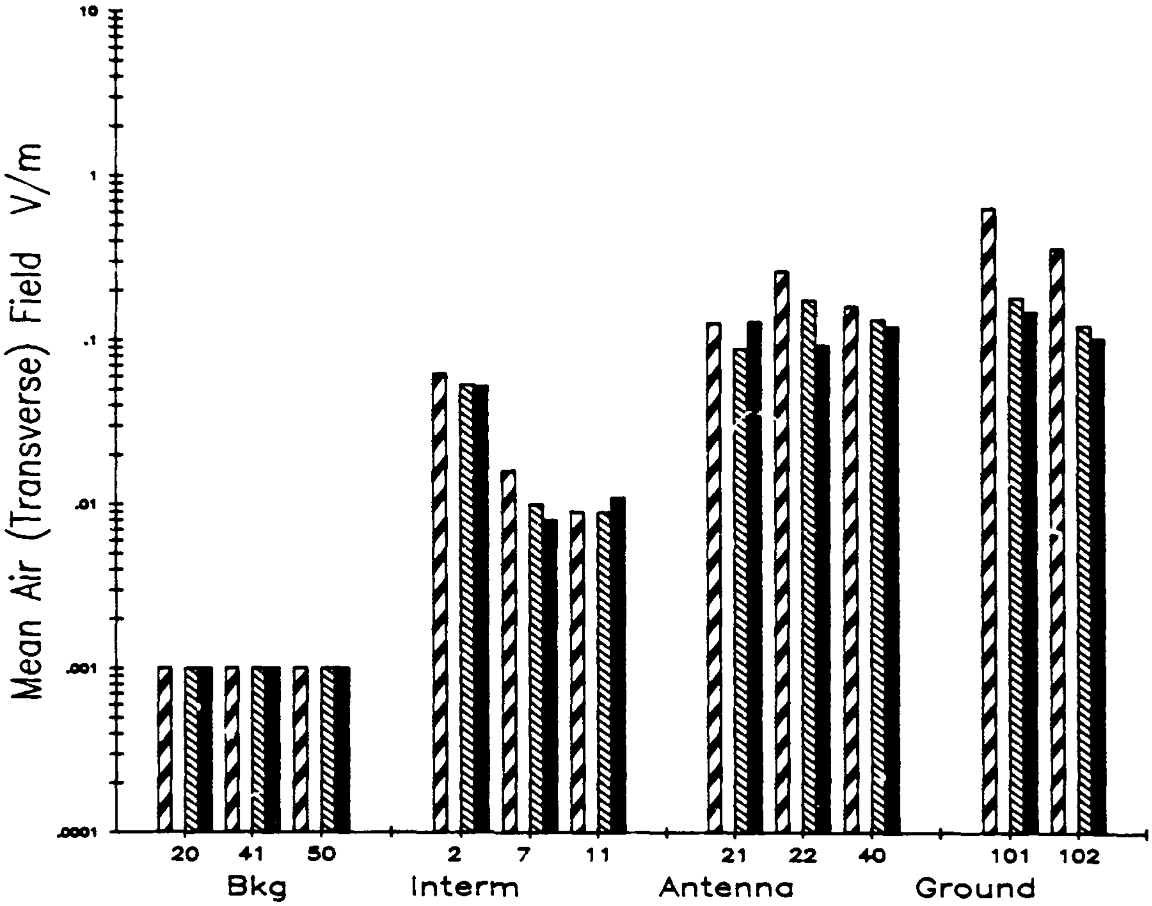


Figure 4.10. Mean electric field measured in air (V / m), measured in each bog in 1984 (wide slash), 1985 (no measurements for air fields), 1986 (narrow slash) and 1987 (black).

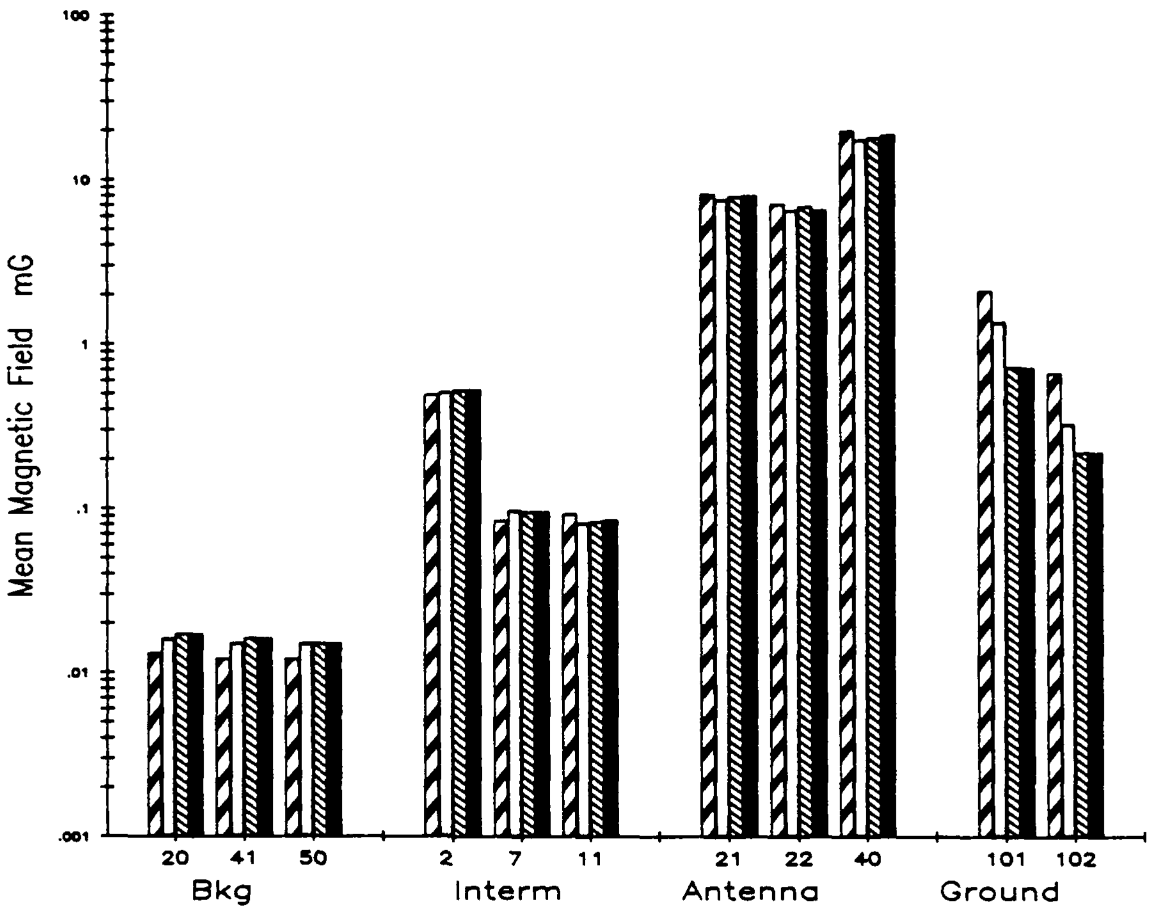


Figure 4.11. Mean magnetic field (mG), as measured in each bog in 1984 (wide slash), 1985 (white), 1986 (narrow slash) and 1987 (black).

Table 4.1. Matrix of Pearson correlation coefficients (r) among the log-transformed ELF electromagnetic field variables from 1987. These values are typical of the relationships between these variables in each year of study (1984 - 1987).

		Correlation Matrix	
	Log air field	Log earth field	Log magnetic field
Log air field	1.000	0.991	0.873
Log earth field	0.991	1.000	0.865
Log magnetic field	0.873	0.865	1.000

DECOMPOSITION STUDIES

Decomposition of organic matter is an important process in all natural systems; the balance between production, decomposition, and export determines the rates of accumulation of organic matter and recycling of various minerals. Decomposition rates tend to be relatively low in wetland systems where saturated substrates, often presenting anoxic and acidic conditions, inhibit microbial activity. Peatlands are extreme examples of systems with low decomposition rates, and the large amount of organic matter in peat, resulting from limited decomposition, is a key character defining this wetland type (Mitsch and Gosselink 1986, Moore and Bellamy 1974).

For northern peatlands, decomposition rates are limited by the following conditions: 1) location in closed depressions leading to waterlogging, 2) low temperatures resulting from latitudinal and topographic location, and 3) acidic water caused by local groundwater conditions (low buffering capacity) and acid-enhancing sphagnum mosses growing in the wetland. Low decomposition rate and accumulation of organic material in the substrate are further enhanced by limited nutrient availability. These conditions are characteristic of the regional groundwater (as seen in the Canadian shield region of the northern Lakes States). Nutrients are also limited through adsorption and cation exchange by the peat. When decomposition rates are increased, for example, through nutrient enrichment or change in the hydrologic regime, major ecosystem-level alterations quickly follow. Guntenspergen, Wikum, and Stearns (pers. comm) have

recorded major changes in both plant species composition and the substrate chemistry of a peatland receiving wastewater discharged from a secondary lagoon. This is an extreme example, but it serves to demonstrate that the unique plant community structure of northern peatlands is closely tied to the geochemistry of the substrate. Slow organic turnover is characteristic of peatland substrates, and decomposition rate is a major feature regulating the system.

We chose to examine decomposition as a critical process in peatland ecosystems, accomplished largely by the microbial community. As a substrate process, microbial decomposition might be altered by electromagnetically induced changes in cell membranes.

GENERAL METHODS

Two approaches were used to examine decomposition rate. The first series of experiments employed pure cellulose as a substrate. Cellulose has been used as a standard material in other studies (Lahde 1969, 1974, Ulehlova 1978, Hundt and Unger 1968, Golley 1960, and Ratliff 1980). Cellulose is a well defined medium representing the chief organic constituent of most plants and thus is a major component of the organic matter of peatlands.

The cellulose used in our studies was in sheet form and had the consistency of blotting paper; as such provided a uniform surface/bulk ratio and contact with the peat. The cellulose used in our experiments was obtained from two sources: 1) The first two experiments used material provided by Dr. Ron Davis (University of Maine); this source material was also being used

in peatland decomposition studies in Minnesota. 2) The remaining experiments with cellulose used material contributed by the Flambeau Paper Corporation, Park Falls, Wisconsin. Both sets of material were produced from bleached pine pulp. Mineral nutrient analyses indicated negligible mineral content.

We pre-weighed square pieces of cellulose (1 gram each) and enclosed each piece in a numbered fiberglass bag (2-3 mm mesh). The bags were inserted vertically into a slit in the peat, below the living moss layer. After several months of incubation, the bags were retrieved, and the cellulose pieces were removed, cleaned of foreign debris, dried and weighed. The proportion of initial weight that was lost over the period of incubation is the unit used in analyses.

Following several sets of experiments, we concluded that, although cellulose offered many advantages for study as a uniform and well-defined medium, it also presented many disadvantages not easily overcome. Variance within groups of samples was persistently high, largely because the cellulose pieces became soft and adhered to the mesh bags, making complete retrieval after incubation extremely difficult.

After completing four experiments with cellulose, we decided to change to a natural litter component, leaves from a common shrub, Labrador Tea (<u>Ledum groenlandicum</u>). This shrub usually has 3 - 4 cohorts of leaves present on the plant during the summer. We collected leaves that were part of the oldest cohort and just about to fall from the plants in September from Background site 41. These leaves had been produced by the plants

during the previous year and would have been the normal contribution to the litter in the Fall. Subsamples of leaves were air dried, weighed (close to 0.5 g), and placed in numbered fiberglass mesh (2 mm) bags. The litter bags were randomly distributed into groups to be placed in each bog. Groups of 4 bags were randomly assigned to treatment bogs and attached along nylon line and placed in hollows (natural shallow depressions) around each well. The individual bags were placed flat on the bog surface among the sphagnum moss, and the line was attached to a fiberglass flag to facilitate retrieval. This placement simulated the natural position of leaves as they fall on the wetland surface and accumulate in hollows. Over the course of the incubation, the moss grew over the sample bags; from this we conclude that conditions for decomposition were reasonably natural and homogeneous. Following incubation and retrieval, the leaves were removed from the bags, cleaned of foreign debris, dried, and reweighed, to determine the proportion of initial weight lost in the incubation period.

The use of Labrador Tea leaves proved to be a good choice because it provided us with a measure of natural litter decomposition, and retrieval of surface samples was more efficient than for cellulose, resulting in lower within-group variance.

SUMMARY OF EXPERIMENTS

Two preliminary short-term pilot studies were completed that, owing to small sample sizes, will not be reported. Over the course of the project, seven major decomposition studies were

completed and are listed with incubation times and sample sizes (Table 4.2). Similar analytical techniques were followed for the cellulose studies and for the Labrador Tea studies. Standard sample statistics are given in Appendix F. The full results of the analyses of variance are included in Appendix G.

PRINCIPAL COMPONENTS ANALYSES OF ENVIRONMENTAL DATA

Since each decomposition study extended over several months, it was appropriate to use environmental variables in each regression analysis that characterized each incubation period in explaining the patterns seen. For each set of samples, all environmental data collected during the incubation period were subjected to a principal components analysis (the rationale for the use of PCA was outlined in the previous section on statistical methods). We assumed that little decomposition occurred between the late fall and early spring environmental measurements. The first and last measurement periods reflect conditions immediately following spring melt and just preceding substrate freezing, respectively. Several principal components analyses involved a large number of variables and resulted in up to ten components eligible for use in regressions (i.e., with eigenvalues >1). In these cases, the loadings were examined to identify logical groupings of high loading variables and to avoid overlap of high loading variables between the components generated in PCA. Usually, the first three to five PCA components were found to meet these criteria and were subsequently used in regression analyses. Results of the principal component analyses

Table 4.2 Decomposition studies conducted between 1983 and 1987. Numbers of samples placed along each bog transect are included.

Study	Duration	Medium	# samples /transect
C 3	Oct., 1983 - June, 1984 (8 months)	Cellulose	50
C 4	Oct., 1983 - Oct., 1984 (12 months)	Cellulose	50
C 5	June, 1984 - Oct., 1984 (4 months)	Cellulose	48
C 6	June, 1984 - June, 1985 (12 months)	Cellulose	48
LT 1	June, 1985 - Oct., 1985 (4 months)	Labrador tea leaves	48
LT 2	June, 1985 - June, 1986 (12 months)	Labrador tea leaves	48
LT 3	Oct., 1986 - Oct., 1987 (12 months)	Labrador tea leaves	96

are summarized in tables that follow. Based on the loadings, we also attempted to interpret which groups of variables were represented by each component.

The design of the first two decomposition experiments (C3 and C4) precluded use of PCA to generate environmental components. Samples were inserted in the peat in ten areas spaced regularly along each transect. However, these sites did not correspond well with the locations of the ground water wells, and thus the well data were not appropriate for use. Variance in the environmental data along each transect was great enough to rule out interpolation.

RESULTS

C3 (October 1983 - June 1984)

Cellulose samples were incubated in the peat along transects in each bog for eight months. Results of a nested analysis of variance indicated no significant ELF treatment effects (Table 4.3). However, significant differences were detected among the bogs. This is evident in the pattern of mean percent weight loss per bog (Figure 4.12). Two sites, Antenna 40 and Ground 101, exhibited high weight loss while Background 19 had the lowest weight loss. However, differences were not consistent among all the bogs within an ELF treatment group. Coefficients of variation (C.V.) ranged from 34 to 160%.

C4 (October 1983 - October 1984)

Cellulose samples were again incubated in peat in each bog for twelve months. Results of a nested analysis of variance indicated no significant ELF treatment effects, although

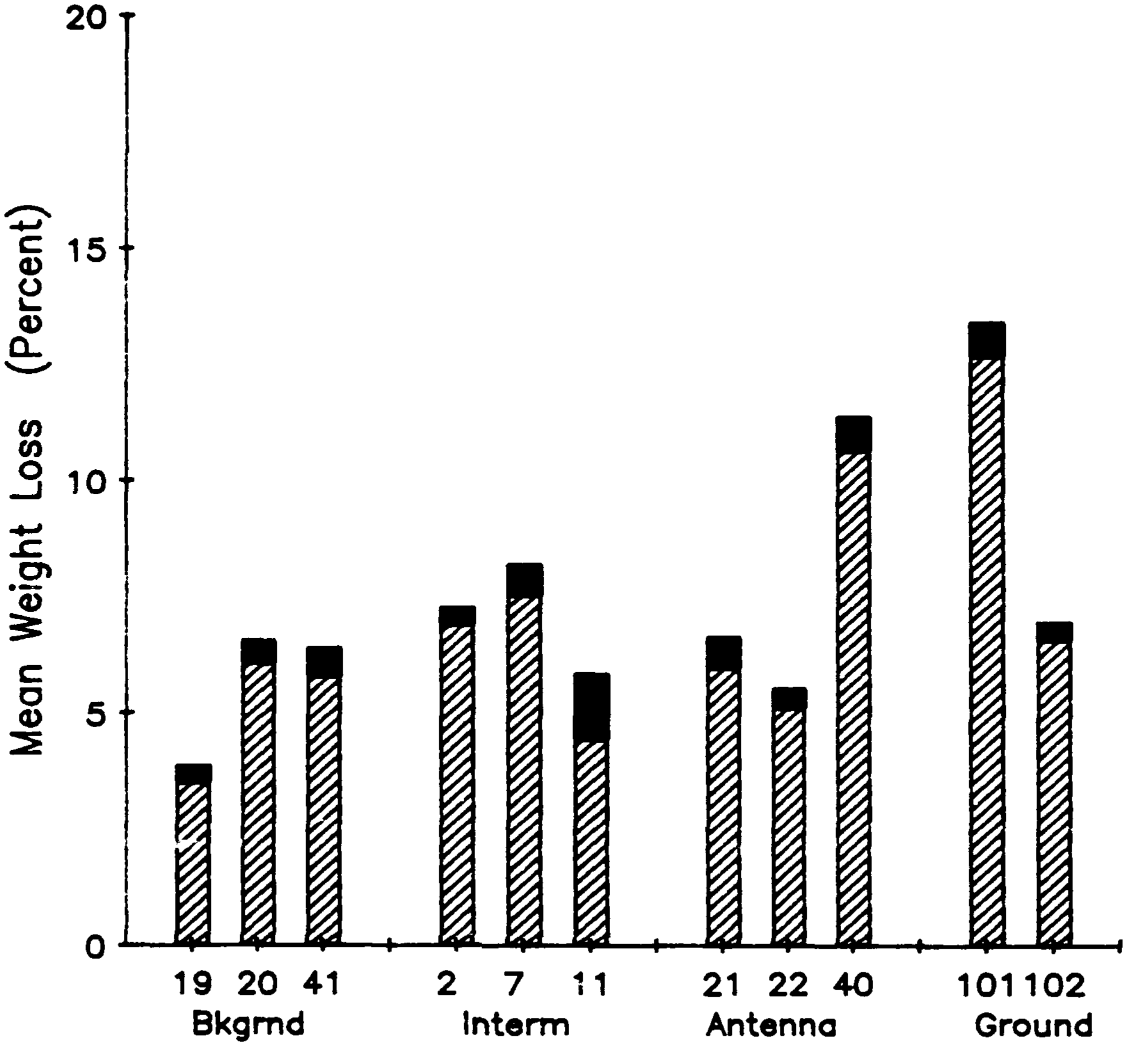


Figure 4.12. Mean (+ 1 S.E.) percent weight loss by cellulose (C3).

Table 4.3. Summary of results from the nested ANOVA for decomposition rate. In each case starting weight is included as a covariate. The dependent variable is weight loss (a proportion of starting weight). F statistics are presented for each level of the analysis;significance is shown by *** (p<.0001), ** (p<.001), * (p<.05), NS= not significant, NA= not tested in model.

Experiment	N	Treatment (ELF level)	Bog (within bog)	Plot
C3	527	1.24 NS	14.87 ***	NA
C4	521	0.19 NS	34.42 ***	NA
C5	495	1.11 NS	5.25 ***	5.36 ***
C6	524	0.47 NS	13.43 ***	3.25 ***
LT1	524	1.25 NS	3.00 *	1.51 *
LT2	527	1.34 NS	4.32 **	1.22 NS
LT3	977	15.54 **	0.71 NS	2.01 ***

significant differences were again present among bogs (Table 4.3). These samples were put in place at the same time as those in C3 but were left in place for an additional four months (over summer). Weight loss by this set was three times greater than in C3. The patterns within treatment types were similar to C3 with the exception of Background 19 (Fig. 4.13). In this site, decomposition reached the highest values found at the end of the 1984 field season as opposed to having had the lowest values in June 1984 (C3). The coefficients of variation for set C4 were lower than for C3, between 25 and 86%.

C5 (June 1984 - October 1984)

This experiment was treated in a similar fashion to C3 and C4, but was incubated for only five months. No differences among ELF treatment types were detected using nested analysis of variance (Table 4.3). There were significant differences among the replicate bogs within treatments (Fig. 4.14). Weight losses within in Bogs 7 and 41 were higher than in the other sites, weight losses in Bogs 20 and 22 were considerably lower. The coefficients of variation remained high (37 to 72 %).

This set of samples had been placed adjacent to our groundwater wells; thus, environmental data were available for interpretation of the patterns. The mean weight losses for samples associated with each well were analyzed with step-wise regression using starting weight, three environmental components and one ELF component (Table 4.4). The three environmental components were selected by the stepwise procedure. Analysis of the standardized regression coefficients suggest that they

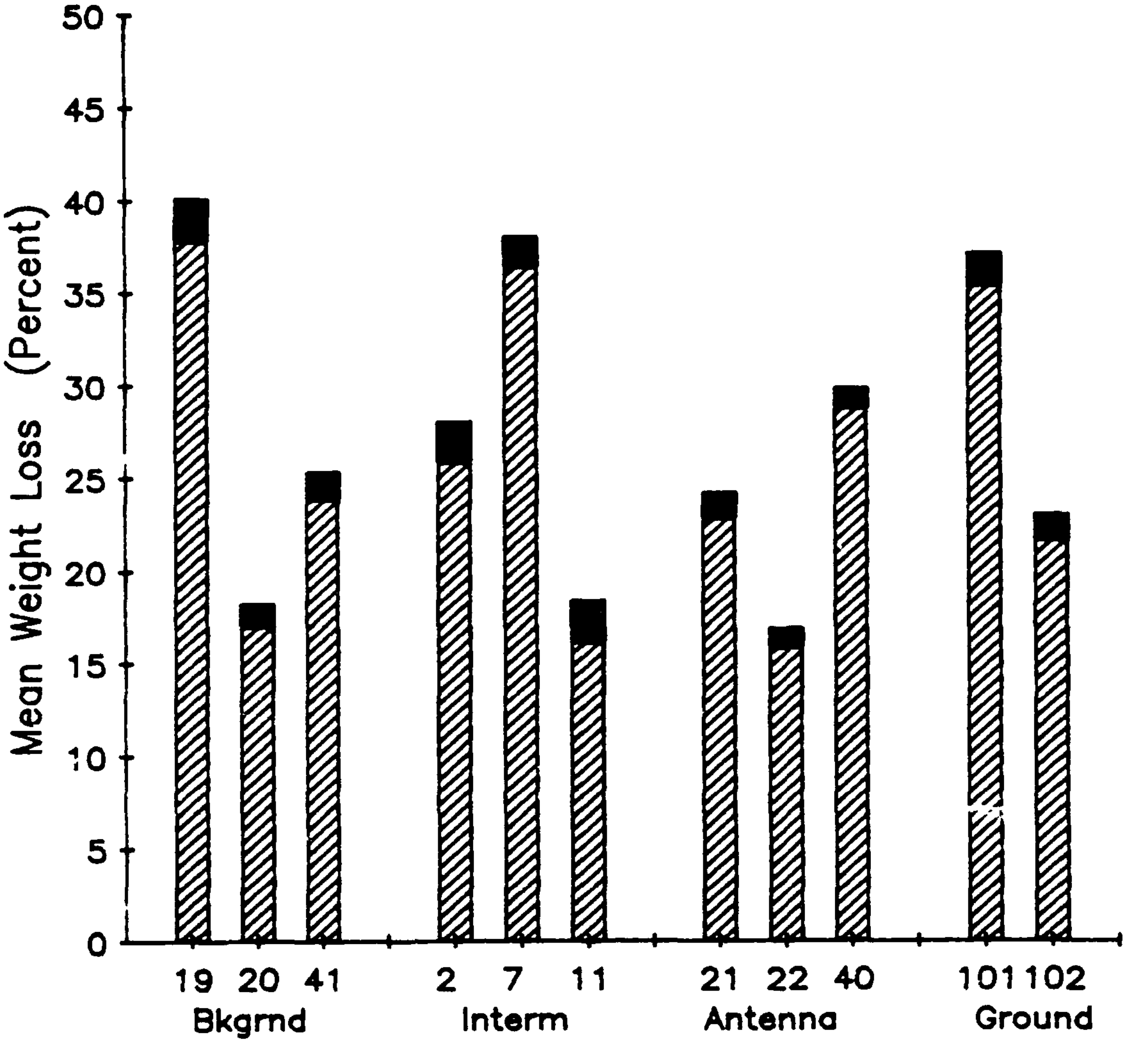


Figure 4.13. Mean (+ 1 S.E.) percent weight loss by cellulose (C4).

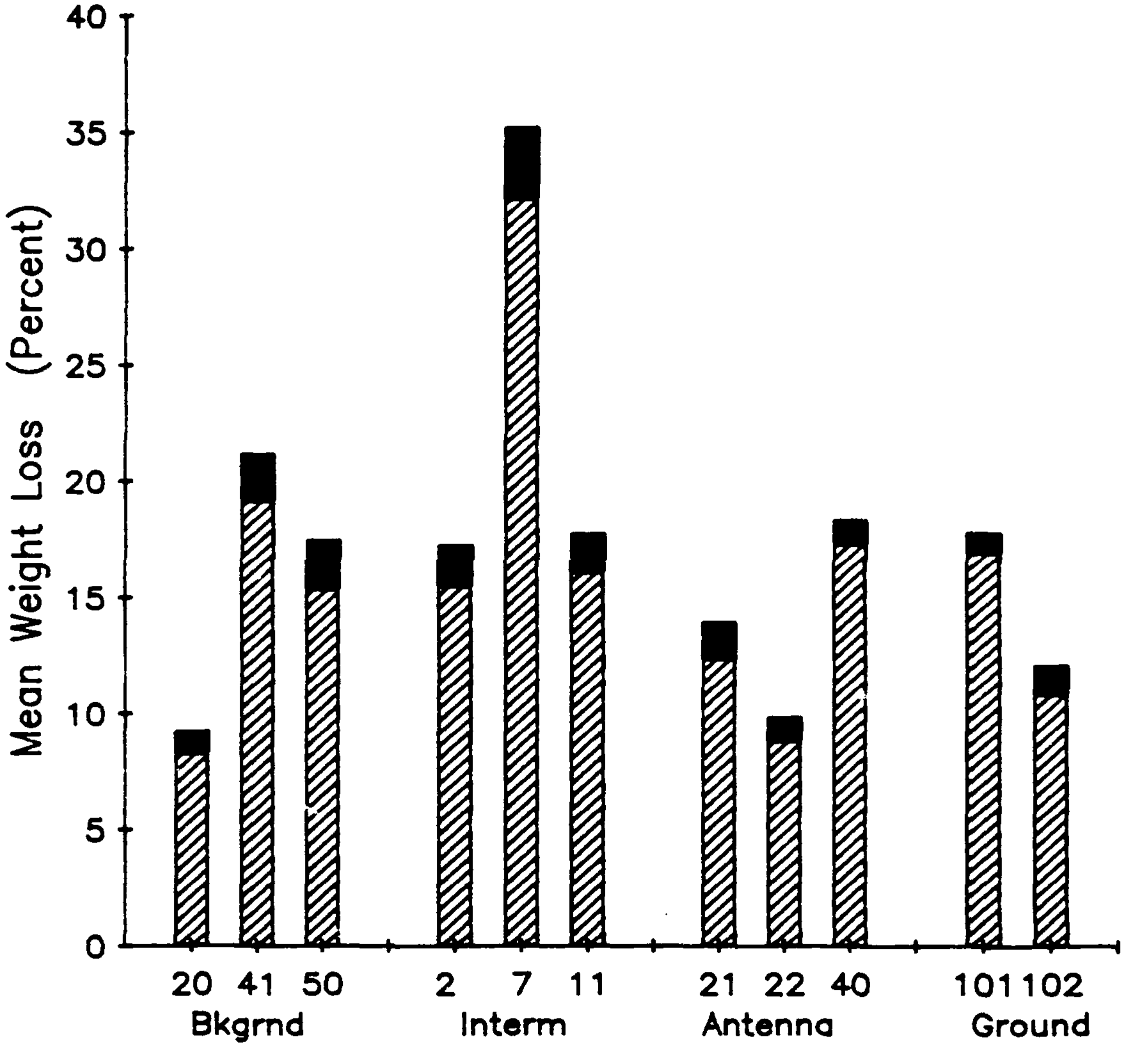


Figure 4.14. Mean (+ 1 S.E.) percent weight loss by cellulose (C5).

Table 4.4 Results of multiple stepwise regression analysis for decomposition rate of standard cellulose over the period June, 1984 through October, 1984 (4 months). Independent variables are principal components representing environmental data: ENV84-1 (divalent cations), ENV84-2 (water depth, conductance, color), and ENV84-3 (temperature). N = 66, T tests B = 0, StB = standardized regression coefficient.

Dependent Variable	Independent Variable	B	T	StB
Weight Loss (proportion)	Intercept	0.1756	17.539	0.0
	ENV84-1	-0.0265	- 2.629*	-0.2675
	ENV84-2	0.0485	4.810*	0.4894
	ENV84-3	0.0215	2.129*	0.2166

R^2 = 0.3270

* = $P < .05$

Independent variables used in the model that were not selected in the stepwise procedure were: Starting weight and ELF84.

influenced decomposition in the following order: ENV84-2 (depth to water table, conductance, color) > ENV84-1 (divalent cations) > ENV84-3 (temperature) and their relationships to decomposition are shown in Figures 4.15 through 4.17. No single variable shows a clear linear relationship. Depth to the water table is a measure of peat aeration, and is expected to have a positive influence on decomposition rate, because water-logged conditions tend to slow breakdown processes. Likewise, decomposition is expected to be directly related to temperature. The negative relationship with Ca^{++} and Mg^{++} is difficult to interpret. It is counter intuitive that "richer sites" (ie. more ionic) would have lower nutrient availability. Together, the three independent variables explain only 32.7% of variance in decomposition, suggesting that other environmental factors are involved.

C6 (June, 1984 - June, 1985)

This was the final experiment using cellulose squares to measure decomposition. These samples were in place over 12 months, beginning in early summer. The pattern across the bogs was similar to that seen in the previous 4-month incubation (Fig. 4.18); weight loss was approximately twice as great after 12 months. Among the Background sites, Bogs 41 and 50 exhibited greater weight losses than Bog 20. Bog 7, typically drier than the other sites, exceeded all others in degree of decomposition.

As before, the results of a nested analysis of variance did not reveal significant differences among ELF treatment types, while differences among bogs were identified. Although still high, coefficients of variation ranged between 29 % and 63 %

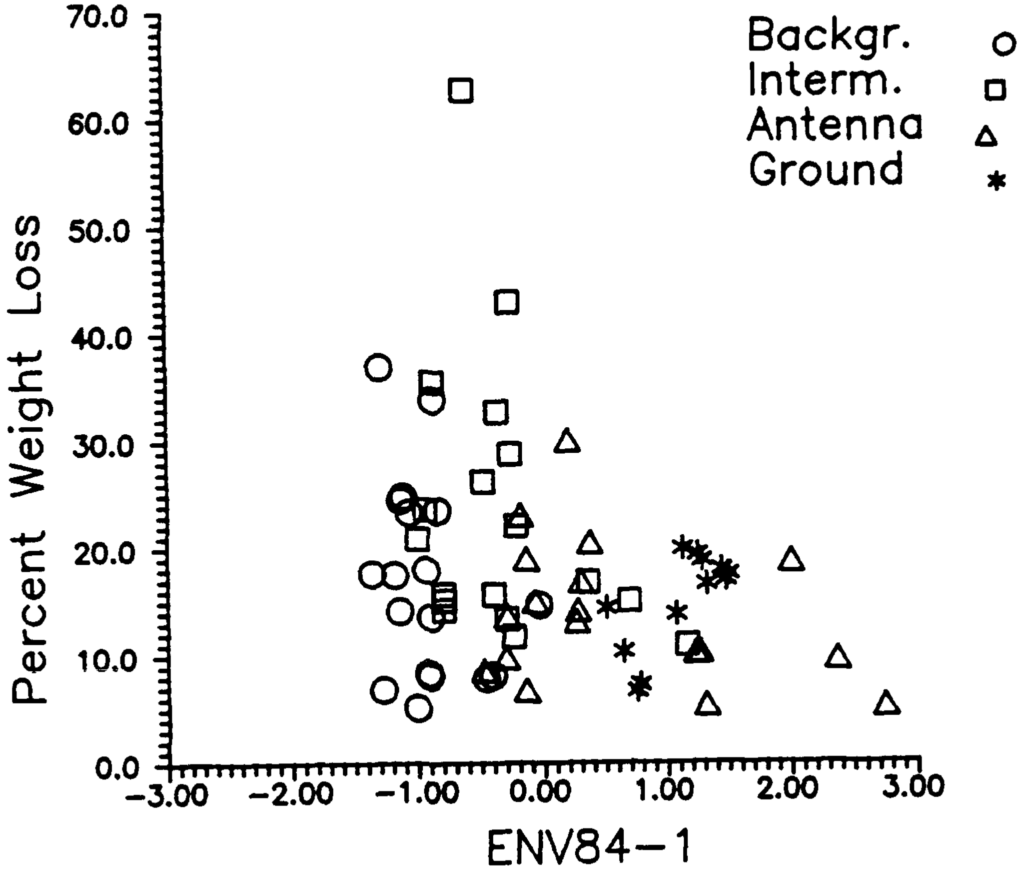


Figure 4.15. Plot of percent weight loss by cellulose (C5) vs. principal component ENV84-1.

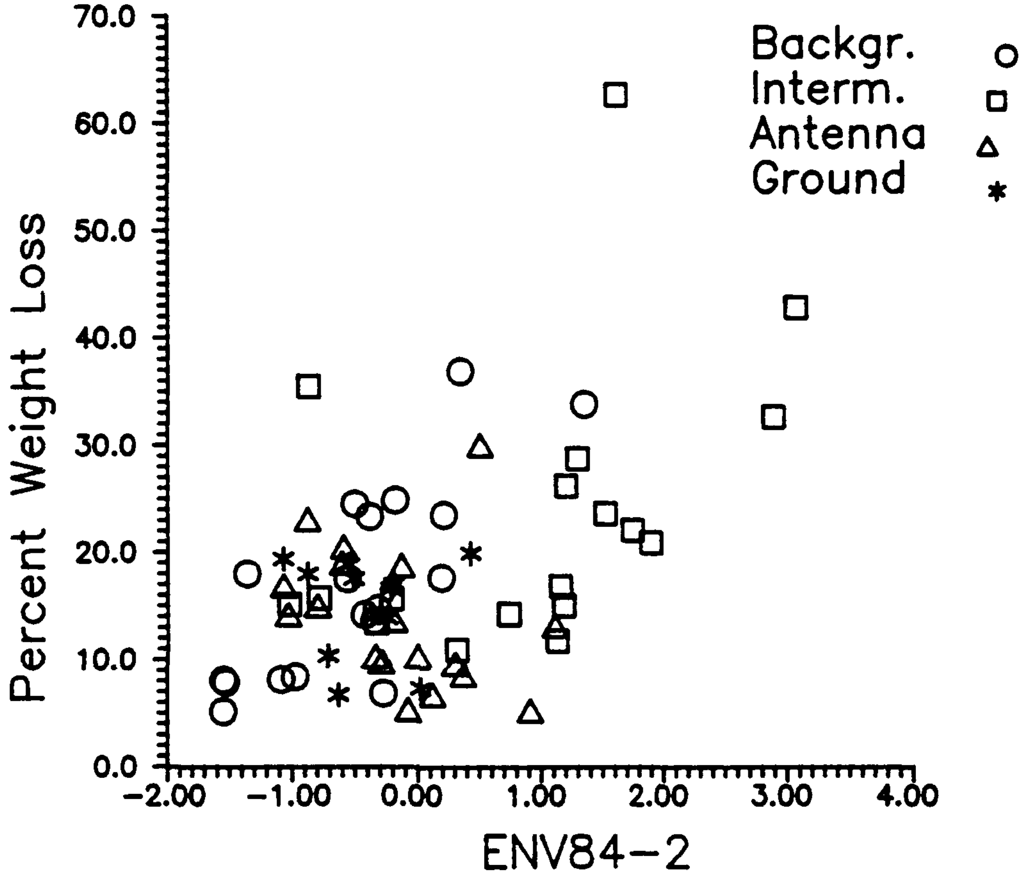


Figure 4.16. Plot of percent weight loss by cellulose (C5) vs principal component ENV84-2.

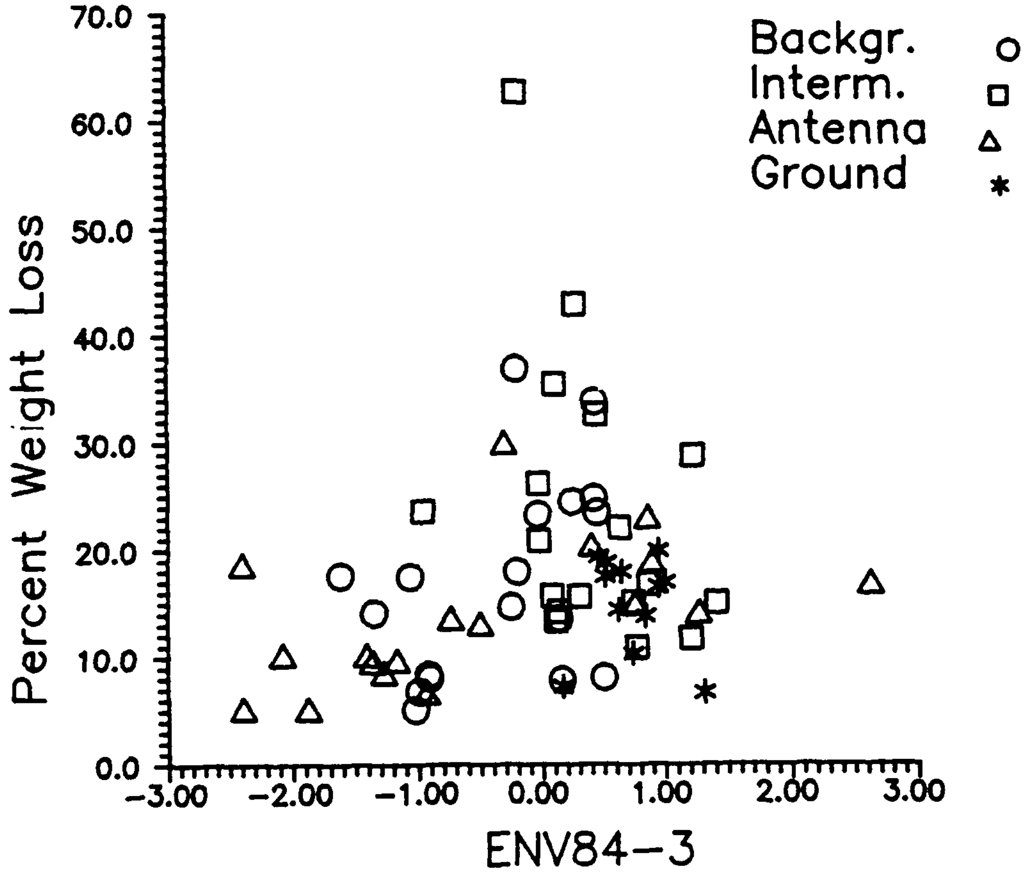


Figure 4.17. Plot of percent weight loss by cellulose (C5) vs principal component ENV84-3.

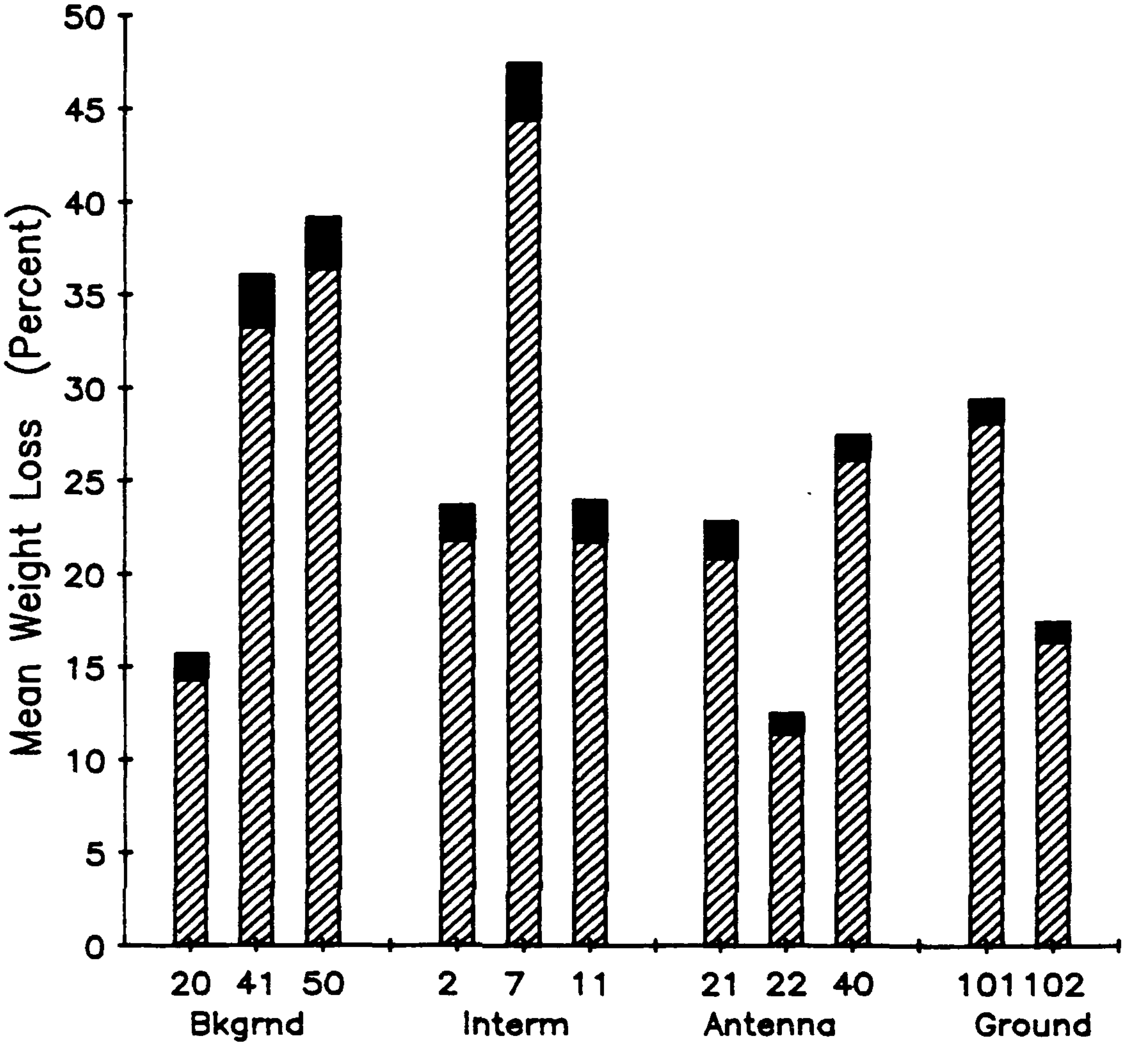


Figure 4.18. Mean (+ 1 S.E.) percent weight loss by cellulose (C6).

(Appendix F), lower than in previous experiments.

This set of samples had been placed in the bogs concurrently with those of C5 adjacent to the environmental test wells. Stepwise regression was used to compare weight losses (means associated with each well) to mean starting weight, five environmental components (E8485-1 through -5) and an ELF component (Table 4.5). The procedure selected the first three environmental components, and using them the model explains 31.3 % of the variance in weight loss.

The three components represent the same environmental features as the previous set (C5), but, the standardized regression coefficients, differ somewhat in their influence on decomposition rate. Here, the order of importance was: E8485-1 (divalent cations) > E8485-2 (depth to the water table, conductance) > E8485-3 (temperature). As in C5, depth to the water table and temperature show a positive relationship and cations a negative relationship to decomposition (Figs. 4.19 - 4.21). By leaving the samples in place for 12 months, we were able to reduce the coefficients of variation (30 - 63 %), but we were not able to explain more of the variance (only 31.3 %).

<u>LT 1 (June, 1985 -- October, 1985)</u>

As outlined earlier, we shifted emphasis toward a material that is a natural part of the peatland litter, leaves of Labrador tea, <u>Ledum groenlandicum</u>. Samples were placed on the bog surfaces in June, 1985. Two groups of four bags were removed from each plot along the transects during the following October after 4 months incubation. Coefficients of variation ranged from 16 % to 29 %; these were considerably lower than values obtained

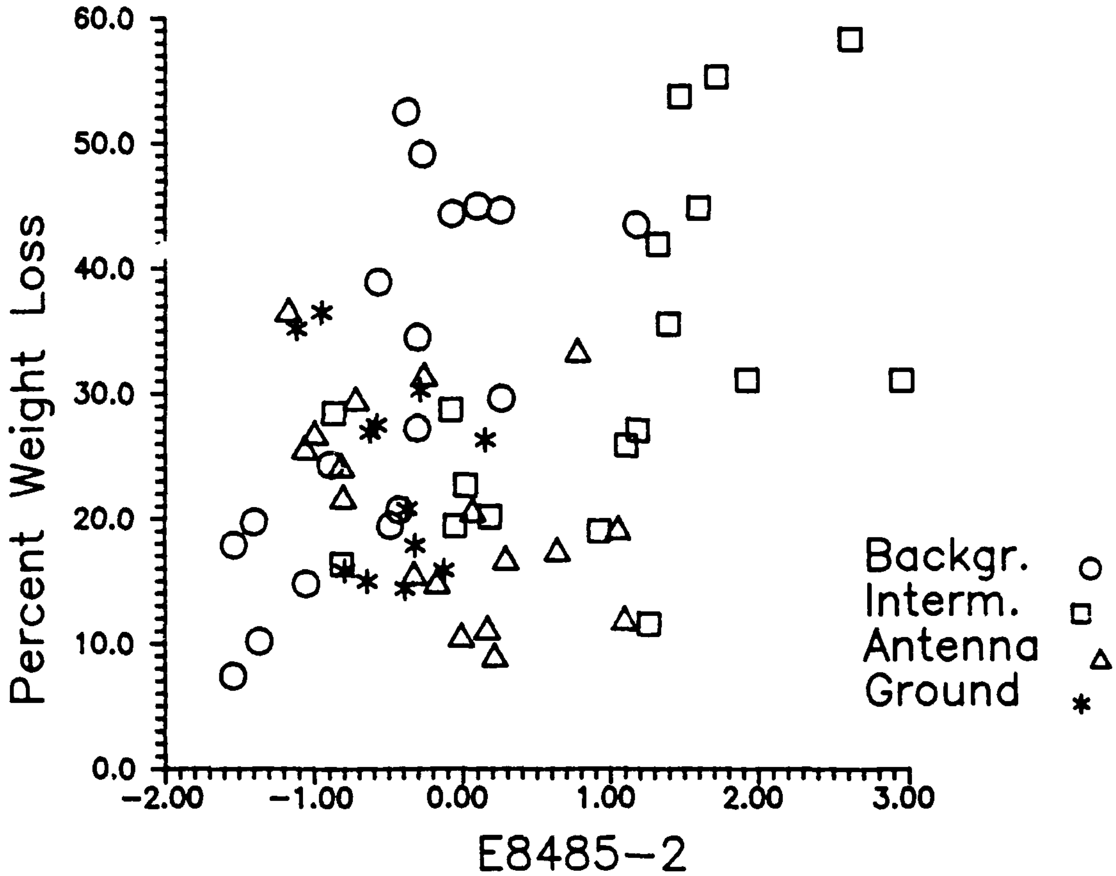


Figure 4.19. Plot of percent weight loss by cellulose (C6) vs environmental principal component E8485-2.

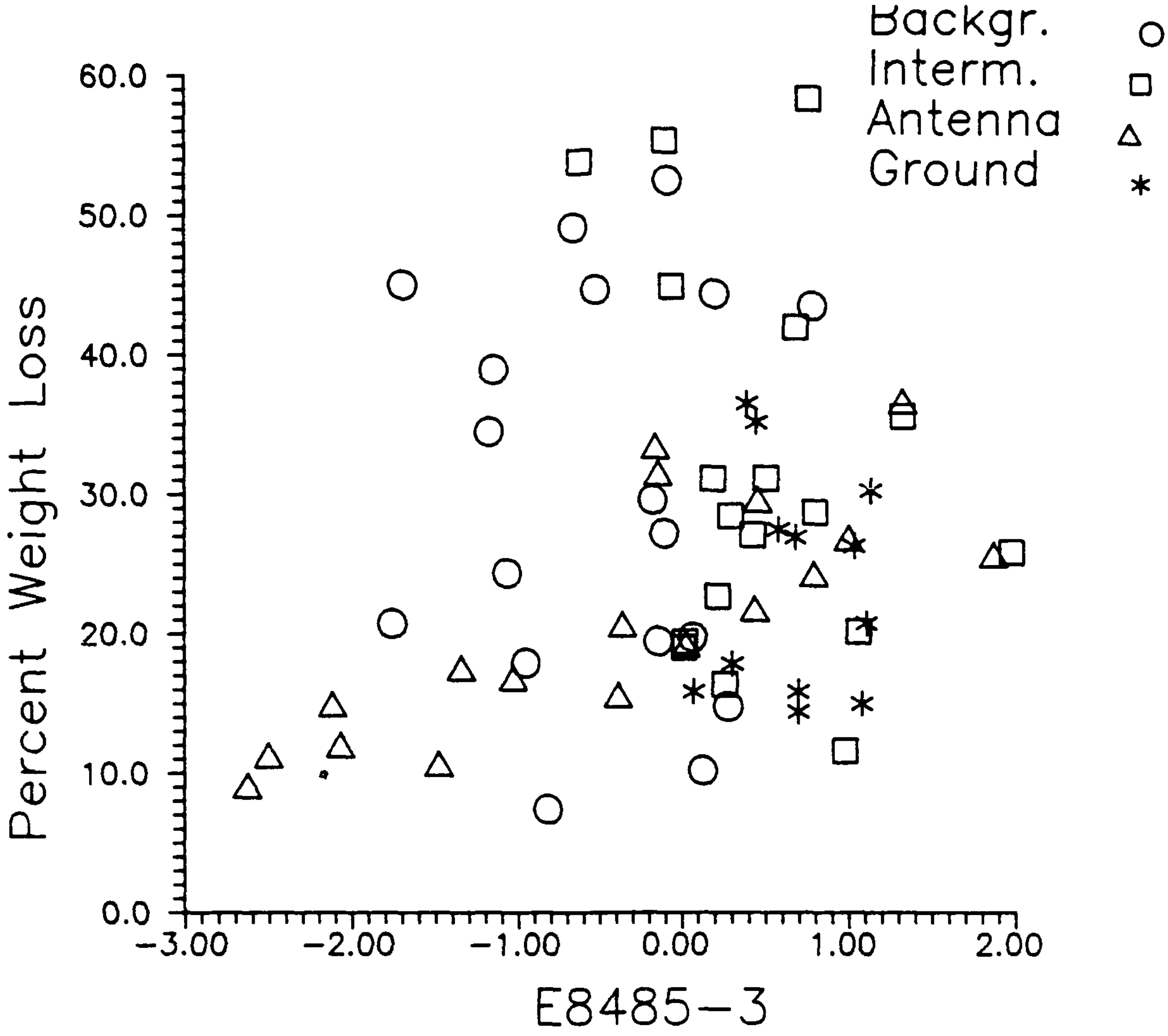


Figure 4.20. Plot of percent weight loss by cellulose (C6) vs environmental principal component E8485-3.

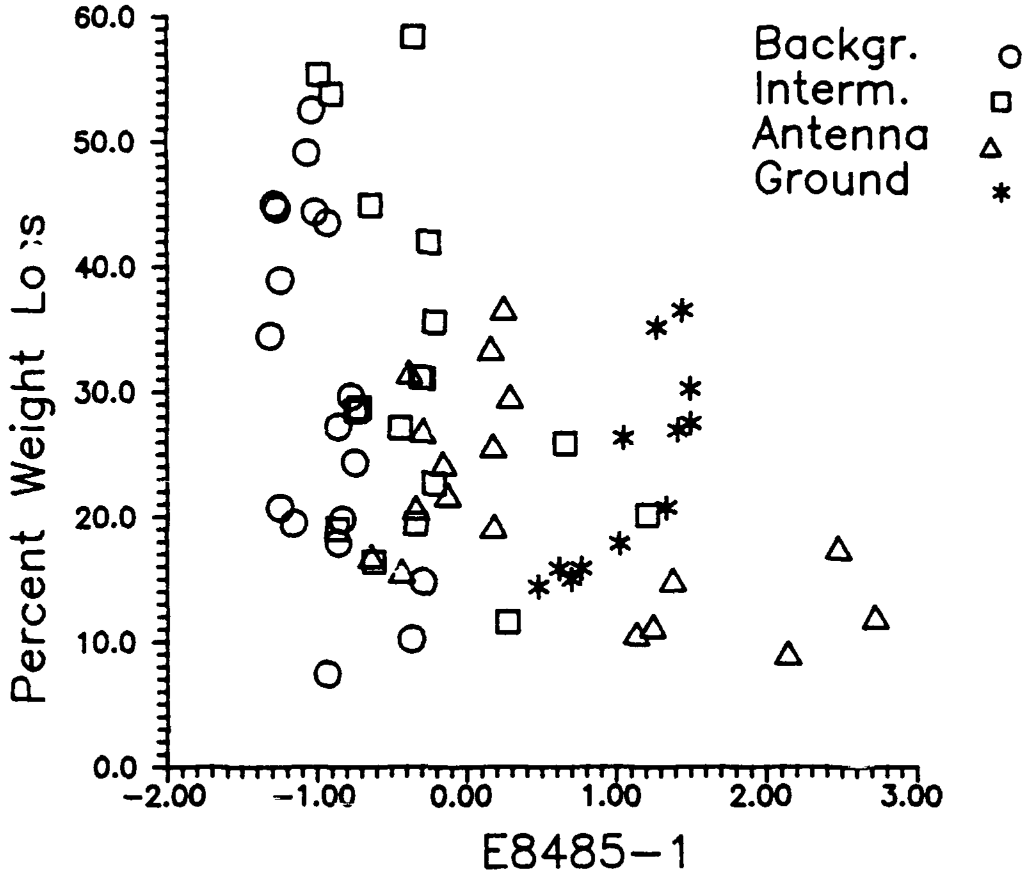


Figure 4.21. Plot of percent weight loss by cellulose (C6) vs environmental principal component E8485-1.

Table 4.5. Results of multiple stepwise regression analysis for decomposition rate of standard cellulose over the period June, 1984 through June, 1985 (12 months). Independent variables are principal components representing environmental data:E8485-1 (divalent cations), E8485-2 (water depth, conductance), and E8485-3 (temperature). N = 66, T tests B = 0, StB = standardized regression coefficient.

Dependent Variable	Independent Variable	B	T	StB
Weight Loss (proportion)	Intercept	0.269	21.289	0.0
	E8485-1	-0.0518	-4.066*	-0.4179
	E8485-2	0.0461	3.619*	0.3720
	E8485-3	0.0222	1.743	0.1791

R^2 = 0.3134

* = P < .01

Independent variables used in the model that were not selected in the stepwise procedure were: Starting weight, E8485-4, E8485-5 and ELF85.

for cellulose weight loss. As in previous analyses, nested analysis of variance failed to detect any differences among ELF treatment types (Table 4.3). Again, there were significant differences among replicate bogs.

The pattern of average values among bogs differs from that seen for cellulose decomposition (Fig. 4.22). Samples from Bog 7 continue to show greater weight loss, but the other bogs do not show the previous pattern.

Stepwise regression was used to compare weight loss (averaged for each plot) with starting weight, four environmental PCA components, and the ELF component (Table 4.6). The procedure selected ENV85-1 (divalent cations) and ELF85 (electromagnetic fields). These two independent variables explained similar amounts of variance in decomposition, but the total explained variance amounted to only 13.7%. When these variables are plotted against weight loss (Fig. 4.23 and 4.24), neither demonstrate a clear relationship. The analysis is clearly inconclusive, since so little variance is explained. Although the ELF component was selected by the stepwise regression procedure, there were no consistent differences among bogs grouped as ELF treatment types.

<u>LT2 (June, 1985 - June, 1986)</u>

Another set of samples was placed on the wetland surfaces in June, 1985. These were allowed to remain in place for 12 months and were retrieved in June, 1986. Weight loss for this experiment exhibited the same pattern as the previous 4-month samples (LT1) (Fig. 4.25). Similar to cellulose, the results for

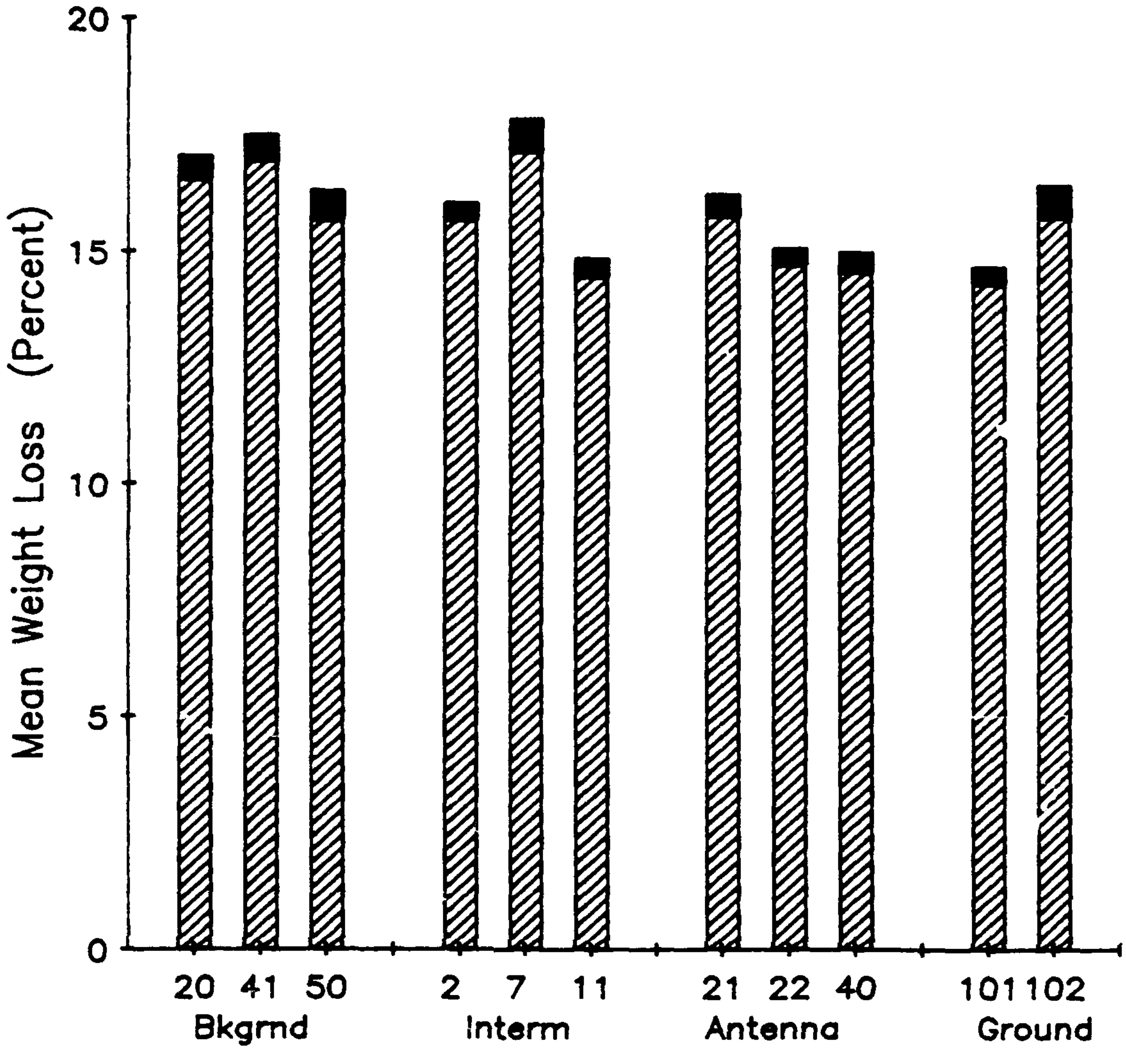


Figure 4.22. Mean (+ 1 S.E.) percent weight loss by Labrador Tea leaves Set 1 (LT1).

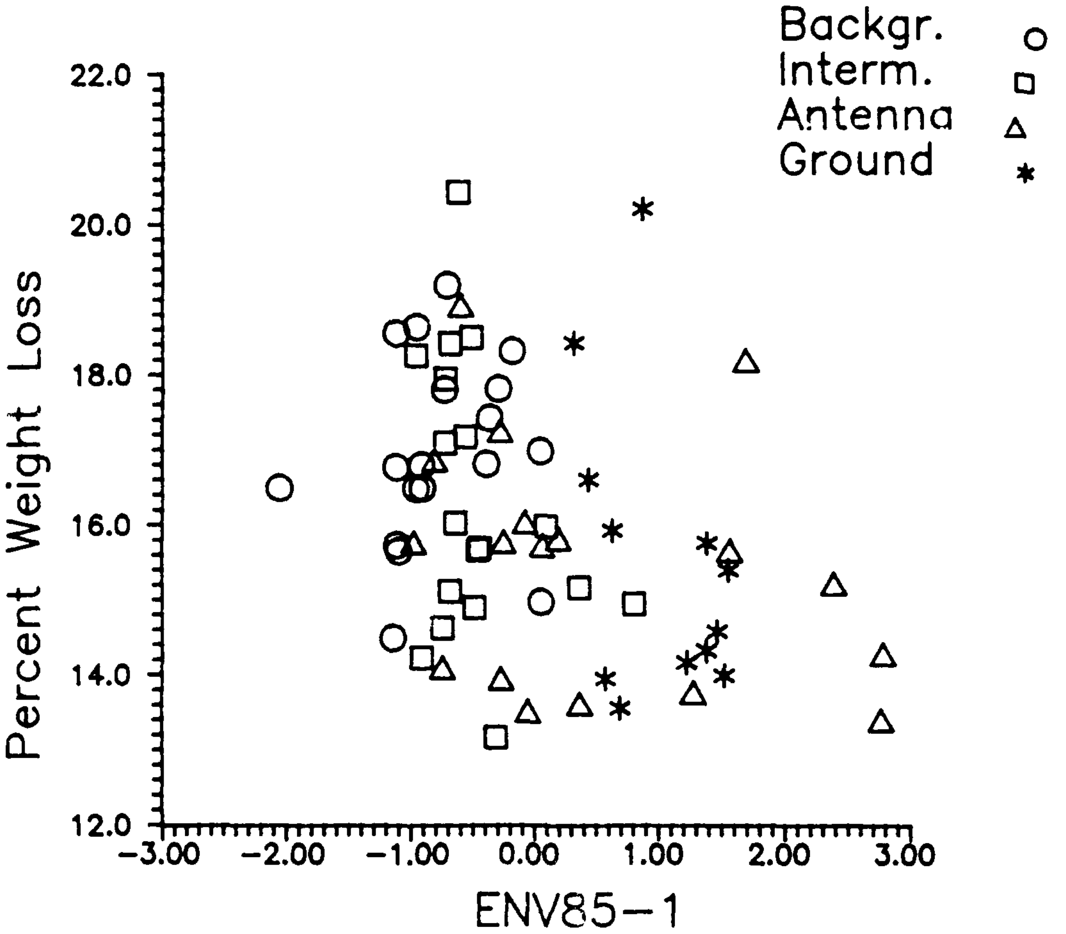


Figure 4.23. Plot of percent weight loss by Labrador Tea leaves, Set 1 (LT1) vs principal component E

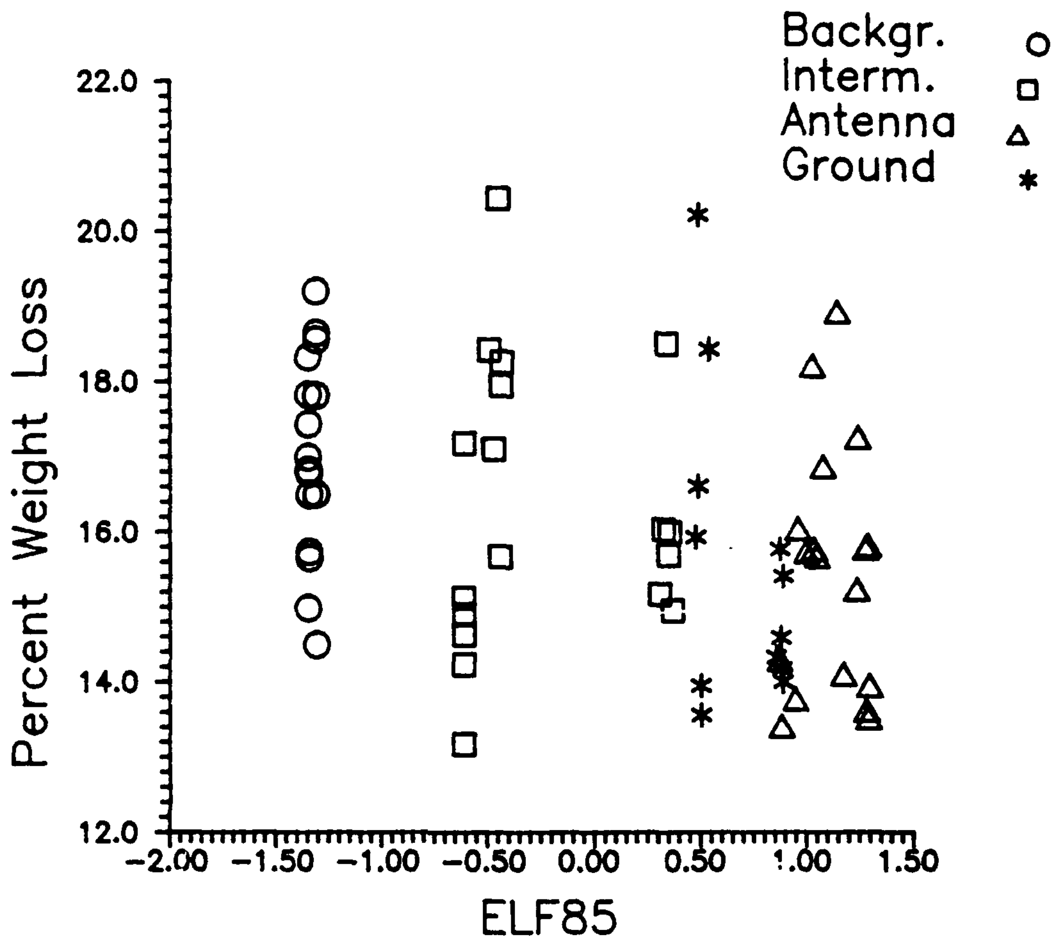


Figure 4.24. Plot of percent weight loss by Labrador Tea leaves, Set 1 (LT1) vs the ELF principal component.

Table 4.6 Results of multiple stepwise regression analysis for decomposition rate of Labrador tea leaves over the period June, 1985 through October, 1985 (4 months). Independent variables are principal components representing : ENV85-1 (divalent cations) and ELF85 (electromagnetic fields). N = 66, T tests B = 0, StB = standardized regression coefficient.

Dependent Variable	Independent Variable	B	T	StB
Weight Loss (proportion)	Intercept	0.1612	79.871	0.0
	ENV85-1	-0.0042	- 1.668	-0.2406
	ELF85	-0.0037	- 1.460	-0.2106

R^2 = 0.1366

Tests for B = 0 were insignificant for both independent variables.

Independent variables used in the model that were not selected in the stepwise procedure were: Starting weight, ENV85-2, ENV85-3, ENV85-4, and ENV85-5.

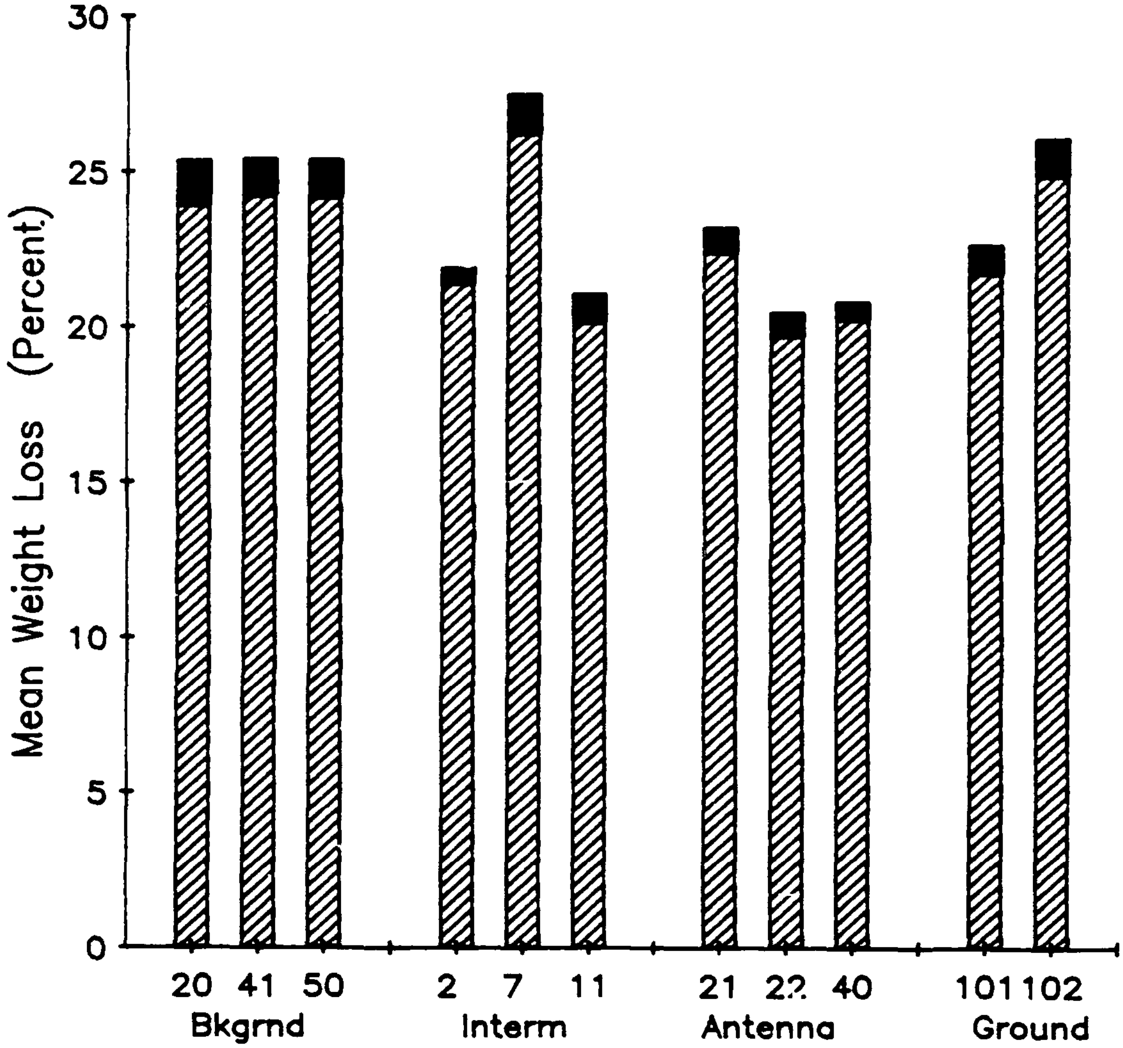


Figure 4.25. Mean (+ 1 S.E.) percent weight loss by Labrador Tea leaves Set 2 (LT2).

Table 4.7 Results of multiple stepwise regression analysis for decomposition of Labrador tea leaves over the period June, 1985 through June, 1986 (12 months). The independent variable (ELF86) is a principal component representing the electromagnetic fields. N = 66, T tests B = 0, StB = standardized regression coefficient.

Dependent Variable	Independent Variable	B	T	StB
Weight Loss (proportion)	Intercept	0.2367	60.127	0.0
	ELF86	-0.0137	-3.447*	-0.3957

R^2 = 0.1434

* = $P < .05$

Independent variables used in the model that were not selected in the stepwise procedure were: Starting weight, E8586-1, E8586-2, E8586-3, E8586-4, and E8586-5.

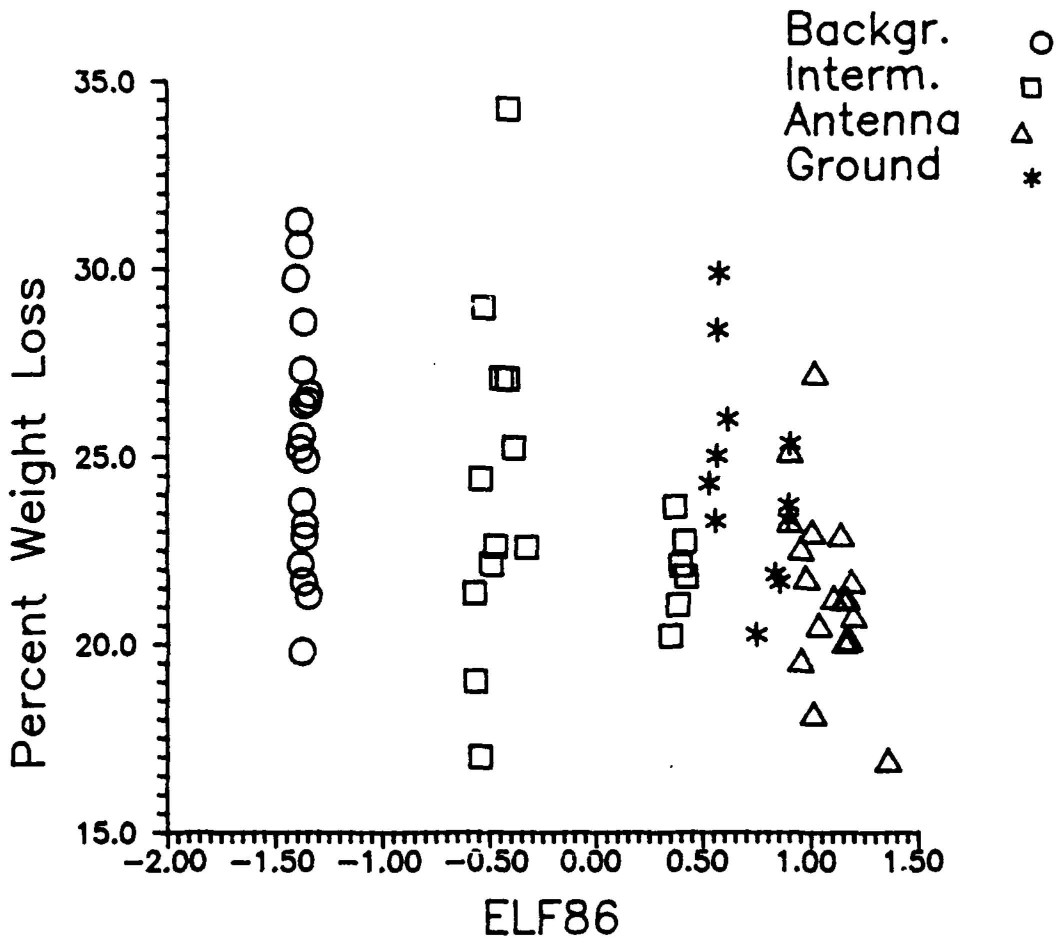


Figure 4.26. Plot of Mean percent weight loss by Labrador Tea leaves, Set 2 (LT2) vs the ELF principal component.

these two sets of Labrador tea leaves show that most breakdown occurs during the summer. While 15 -20% of the weight loss was lost between June and October, the samples lost only an additional 5 - 10% by the following spring. Coefficients of variation were somewhat higher for this data set than for LT1, ranging from 18 % to 39 % (Appendix F).

While significant differences between bogs were again identified using nested analysis of variance, there were no significant differences among ELF types (Table 4.3). After subjecting the average values for each plot to a stepwise regression procedure with starting weight, five environmental components, and the electromagnetic field component, the latter, ELF86, was selected as the only independent variable meeting the correlation requirement (Table 4.7). However, only 14.3% of the variance in decomposition rate was explained. The plot of weight loss vs. ELF86 (Fig.4.26) does not show any clear pattern. Decomposition by this set of samples clearly does not relate well to the environmental information available. Likewise, despite selection in the stepwise regression procedure, ELF fields explain very little of the variance.

LT3 (October, 1986 -- October, 1987)

In 1986, in an attempt to reduce the within-bog variation, sample size was increased from 48 to 96 samples per transect. From a power analysis of previous experiments, this sample size was expected to provide an 80% certainty of detecting a 20% difference among sample means ($p < .05$) (Zar 1987), whereas, to detect a 10% difference among sample means, 439 samples/bog would be required.

Techniques for collection of leaves and sample preparation were similar to the previous experiment. As before, leaves were collected from Background Bog 41; samples were left in place for 12 months and processed to determine proportion of weight loss (Fig. 4.27).

Coefficients of variation in this experiment were lower than values for the previous 12 month samples (LT2) and are more consistent among sites. Unlike previous experiments, nested analysis of variance did not detect differences among bogs, but significant differences among ELF treatment types were identified. Results of an unplanned multiple comparison of means indicated that the samples from the Antenna treatment bogs exhibited greater weight loss than the other three treatment types, and that decomposition in the Background treatment exceeded that in the Ground treatment.

Previous experience had shown that the sphagnum moss tended to grow unevenly over the litter bags. In an attempt to measure this in this experiment, we scored the amount of moss cover over each bag at the time of retrieval using a five point rating system:

0 - bags lying in standing water

1 - bags completely covered by growing moss

2 - greater than 50% cover by moss

3 - less than 50% cover by moss

4 - completely uncovered.

Only 4 out of 1052 litter bags fell into category 0, so this category was eliminated in subsequent analyses. A 4 X 4

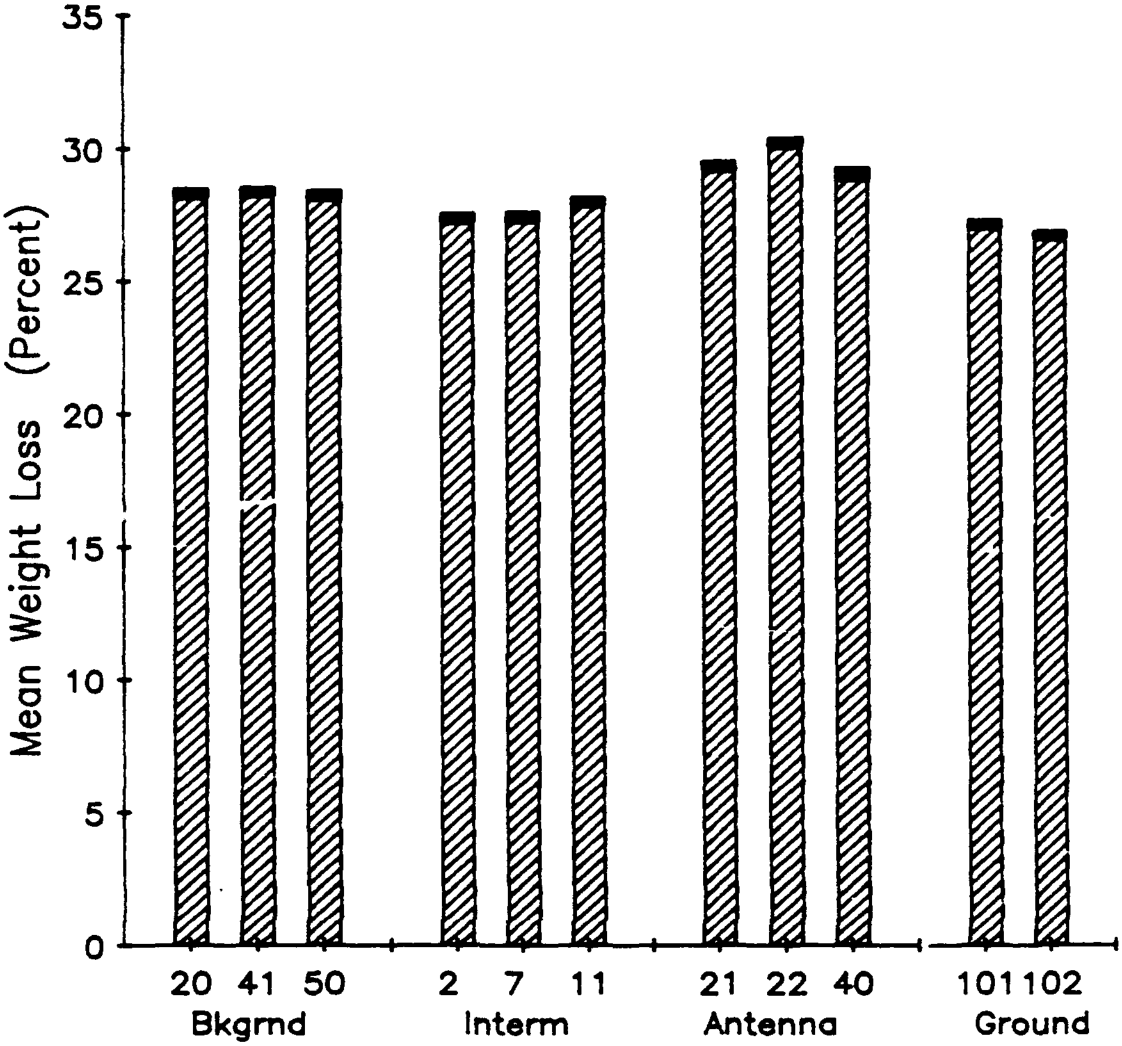


Figure 4.27. Mean (+ 1 S.E.) percent weight loss by Labrador Tea leaves Set 3 (LT3).

contingency table was used to determine whether the microenvironment of the litter bags was independent of ELF treatment type. We concluded from this analysis that moss cover was not independent of treatment type (x^2 = 136.33, 9 df, $p<.05$). For instance, 62 % of the Antenna litter bags were completely covered by moss, but only 35 % and 25 % of the Intermediate and Background litter bags, respectively, were covered (Fig. 4.28). In addition, there were significant differences in weight loss between moss cover classes when all the decomposition samples were pooled (one-way ANOVA, N=1053, F=19.03, $p<.0001$). Since the microenvironmental conditions for litter bags were not uniform across treatment groups, this may explain the significant ELF treatment effect found in the analysis of variance.

Mean weight loss associated with the plots along each transect were subjected to stepwise regression analysis, using starting weight, five environmental components, and a component representing the ELF fields as independent variables (Table 4.8). The ELF component was not selected, but three environmental components were chosen. The resulting model explained only 24.4% of the variance. Based on the standardized regression coefficients, the selected components influence the dependent variable in the following order: ENV87-3 (Fall temperature, pH) > ENV87-4 (Spring temperature) > ENV87-2 (depth to water table, conductance). Each independent variable is plotted against weight loss (Fig. 4.29 - 4.31). No single independent variable shows a clear relationship to decomposition.

The patterns shown for Labrador Tea leaves differ from the relationships between cellulose decomposition and environment.

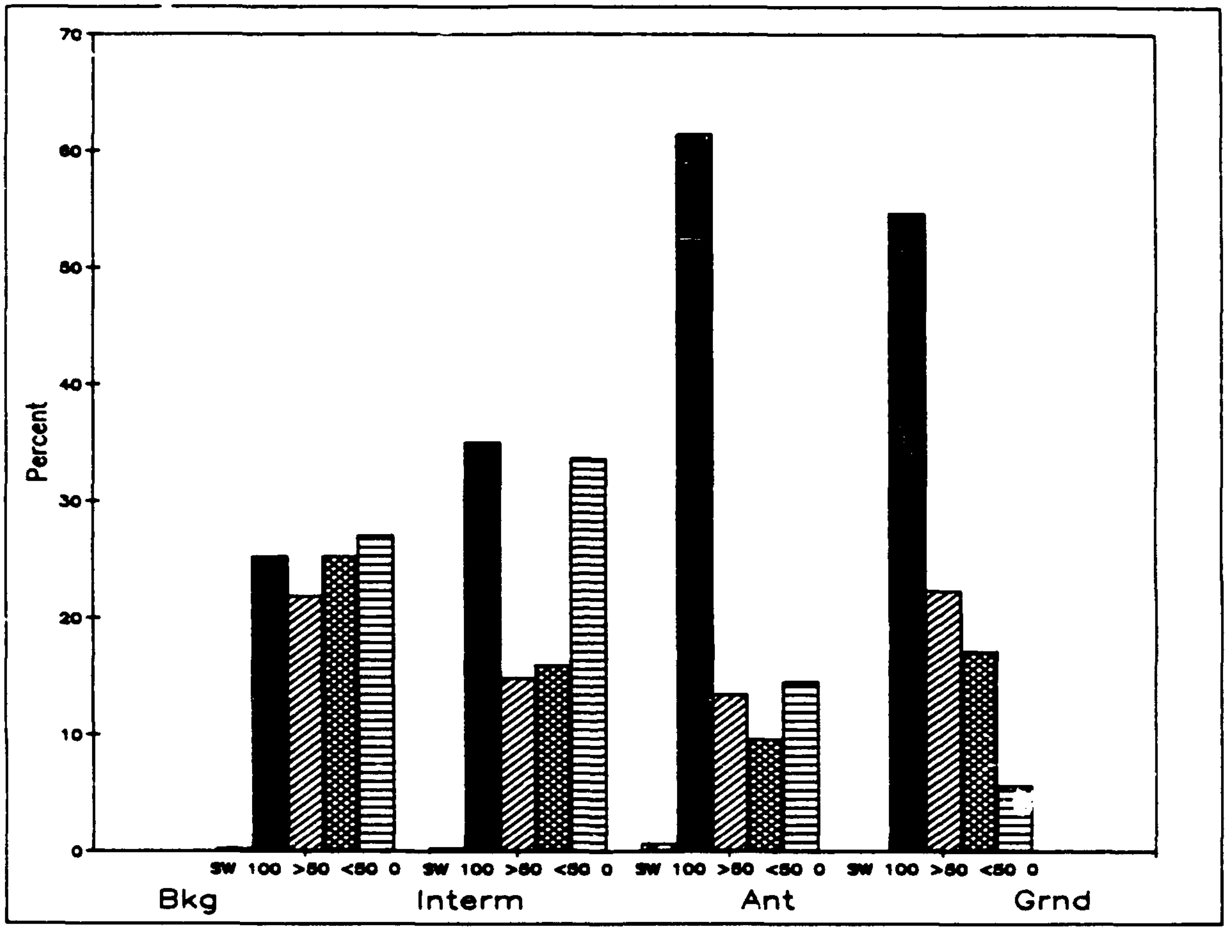


Figure 4.28. Distribution of placement classes of litter bags within each ELF treatment type (percent of all bags within each type). SW = covered by standing water; moss cover classes = 100%, <50%, >50%, 0%.

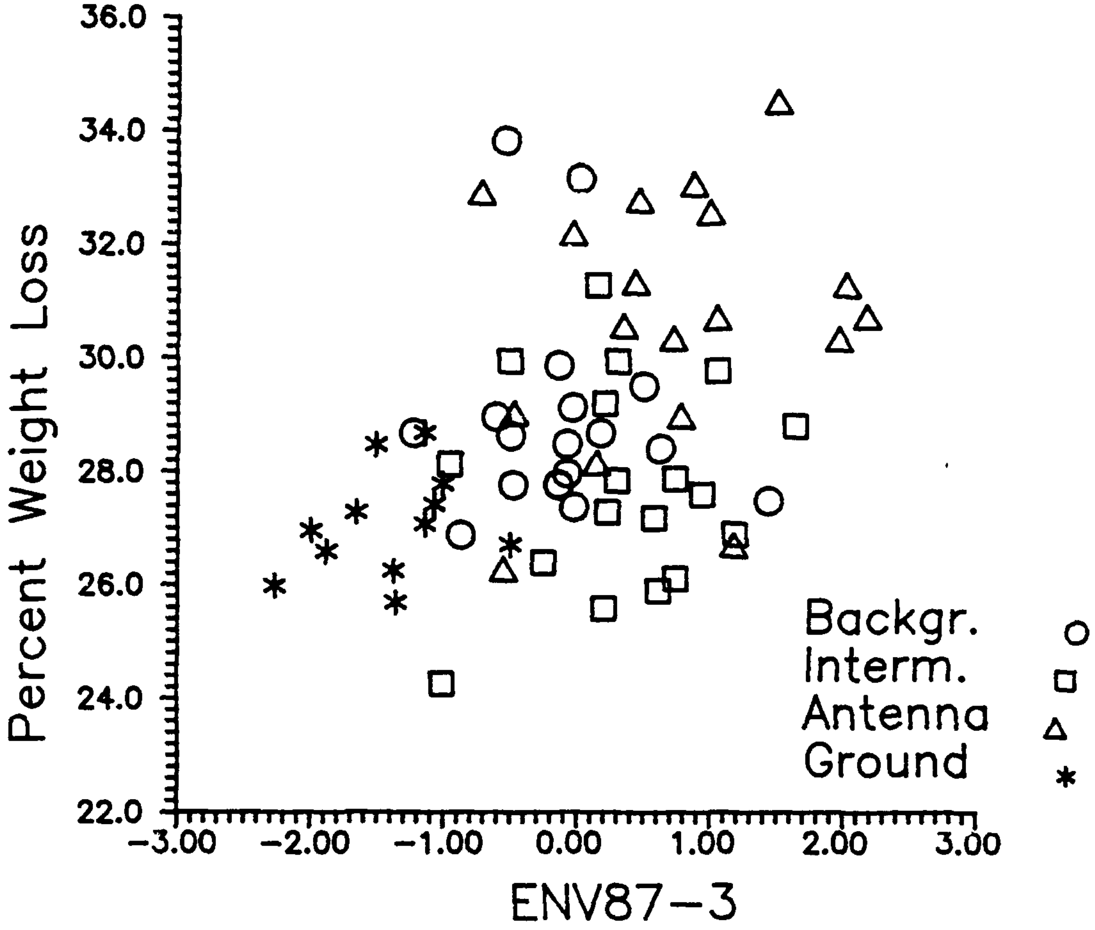


Figure 4.29. Plot of percent weight loss by Labrador Tea leaves, Set 3, (LT3) vs. principal component ENV87-2.

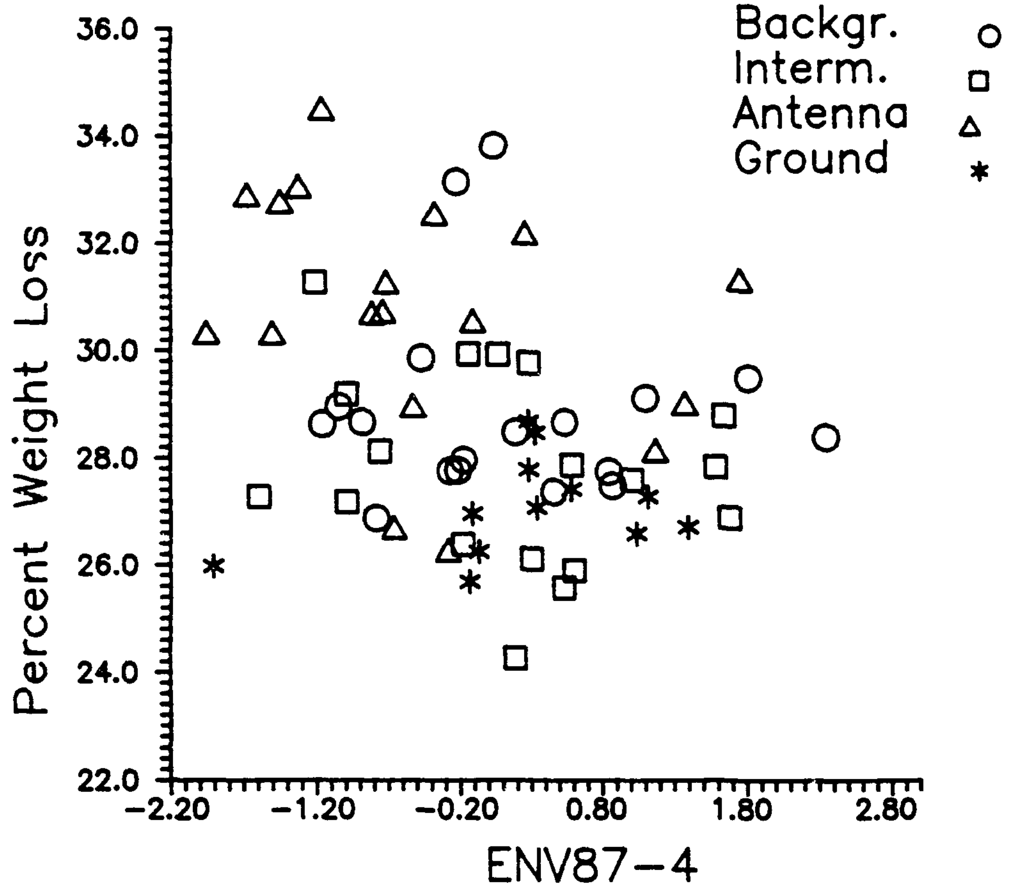


Figure 4.30. Plot of percent weight loss by Labrador Tea leaves, Set 3, (LT3) vs. principal component ENV87-4.

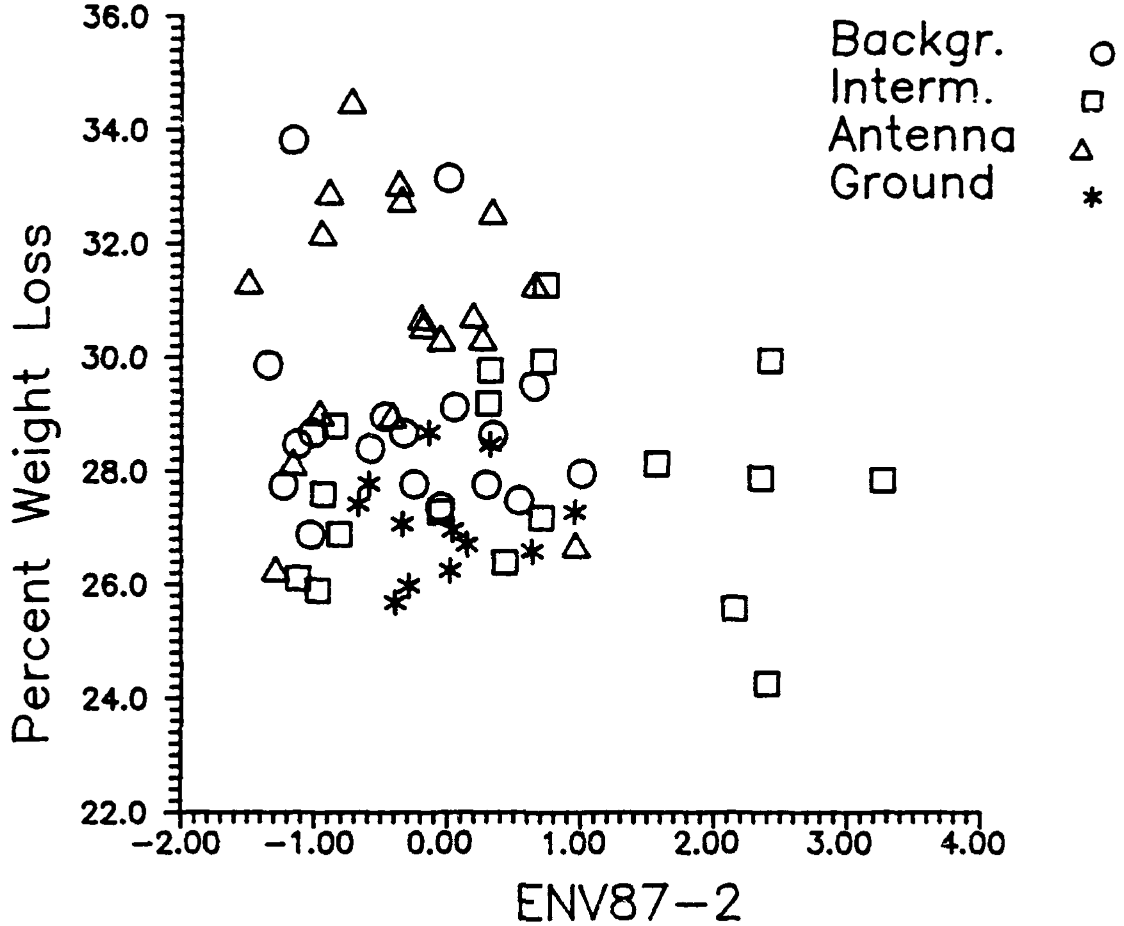


Figure 4.31. Plot of percent weight loss by Labrador Tea leaves, Set 3, (LT3) vs. principal component ENV87 - 2.

Table 4.8 Results of multiple stepwise regression analysis for decomposition rate of Labrador tea leaves over the period October, 1986 through October, 1987 (12 months). Independent variables are principal components representing environmental data: ENV87-2 (water depth, conductance, color), ENV87-3 (fall temperature, pH, and ENV87-4 (spring temperature). N = 66, T tests B = 0, StB = standardized regression coefficient.

Dependent Variable	Independent Variable	B	T	StB
Weight Loss (proportion)	Intercept	0.2875	120.080	0.0
	ENV87-2	-0.0044	-1.832	-0.1976
	ENV87-3	0.0087	3.599*	0.3881
	ENV87-4	-0.0067	-2.773*	-0.2990

R^2 = 0.2441

* = P < .05

Independent variables used in the model that were not selected in the stepwise procedure were: starting weight, ENV87-1, ENV87-5, and ELF87.

"Depth to the water table/conductance" (ENV87-2) is inversely related to Labrador Tea leaf breakdown. This implies that groundwater near the surface contributes to increased decomposition. This is logical for surface material that decomposes more rapidly under wet conditions. As with cellulose, higher temperature, especially in summer and fall (ENV87-3) coincides with greater decomposition. The negative relationship between Spring temperature (ENV87-4) and weight loss is not easily explained. Because we measured "temperature" as groundwater temperature, low values in Spring may be evidence of an extremely cold winter with abundant ice in the bogs; freeze-thaw activity near the surface, capable of weakening or breaking the litter samples, could result in greater weight loss.

SUMMARY

The studies of decomposition, both of standard cellulose and of Labrador tea leaves, have been successful in some respects and unsuccessful in others. The patterns of decomposition in both sets of experiments were consistent across each group of experiments, so we are confident that we have reasonable estimates of decomposition up to one year in duration. Furthermore, by using natural plant material and increasing the sample size, we were able to reduce the coefficient of variation within each bog to a reasonable level.

We have not been successful in statistically explaining much of the variance in decomposition. We were able to explain only 30 - 35% of the variance in cellulose breakdown and 32% of variance

Table 4.9 Summary of results of regression analyses for decomposition in wetlands surrounding the WTF. Independent variables are general interpretations on principal components. STB = standardized regression coefficient.

Study	Duration	Medium	Selected Independent Variables	STB	R^2
C 5	4 months	Cellulose	Water depth/ conductance	0.489	.33
			divalent cations	-0.268	
			temperature	0.217	
C 6	12 months	Cellulose	divalent cations	-0.418	.31
			water depth/ conductance	0.372	
			temperature	0.179	
LT 1	4 months	Lab. tea	divalent cations	-0.241	.14
			ELF fields	-0.211	
LT 2	12 months	Lab. tea	ELF fields	-0.396	.14
LT 3	12 months	Lab. tea	Fall temp/ pH	0.388	.24
			Spring temp	-0.299	
			Water depth/ conductance	-0.198	

in Labrador tea leaf decomposition (Table 4.9). The subsurface (cellulose) decomposition variance is likely influenced by sample retrieval problems; cellulose becomes fragile and fragments are easily lost from the mesh bags after incubation. With Labrador Tea leaves, surface phenomena influenced breakdown. By categorizing the moss cover of the litter bags, we found that more litter bags in the Antenna plots were completely covered and these samples also showed higher weight loss. Also, in 1987, depth to the water table was found to be inversely related to weight loss. This implies that leaf decomposition occurs at a faster rate in a moist environment among the surface moss.

In these studies, ELF electromagnetic fields have not been shown to influence decomposition rate. The significant ELF treatment effect seen in the nested analysis of variance in 1987 appears to have been influenced by moss coverage of litter bags. Furthermore, the stepwise regression procedure for that experiment did not select the ELF component as having any correlation with weight loss. In earlier experiments, ELF components were selected by the stepwise regression procedure. However, in LT-1, the slope of the relationship (B) was not different from 0, and the variance explained in these analyses amounted to only 14%. These cannot be considered statistically significant results.

STOMATAL RESISTANCE

Stomatal resistance has been examined as a correlate of the physiological status of wetland plants exposed to ELF electromagnetic fields from the Wisconsin Transmitter Facility. Because electromagnetic fields have been hypothesized to operate at the membrane level, it is possible that they may affect the regulation of stomatal opening or closing either directly or indirectly.

The stomata regulate water vapor and gas exchange between the atmosphere and the leaf. They are effective in this role because of their capacity to open and close in response to factors such as light, carbon dioxide concentration, plant water status, humidity, wind, etc. Other factors influencing stomatal behavior include leaf age, nutrition, and disease.

ELF electromagnetic field effects may indirectly affect stomatal resistance of leaves by altering the effectiveness of water uptake or directly by affecting the mechanisms controlling stomatal movement, e.g. guard cell or mesophyll water status as mediated by osmotic pressure.

We used a null-balance type diffusive resistance porometer (reference) to measure the rate of water vapor diffusion from the leaves through the stomates. This type of porometer uses a humidity sensor to detect changes in humidity caused by water vapor loss. The leaf is fixed to a chamber with an attached fan to mix the air and minimize chamber boundary layer resistance.

In 1985, we initiated preliminary measurements designed to choose a test species and to monitor the behavior of leaf

diffusive resistance under a varying set of environmental conditions. This allowed us to establish a set of operating conditions for our sampling protocol. For instance, light is important in regulating stomatal behavior. Maximal stomatal aperture usually occurs when sun leaves are exposed to greater than 1/4 full summer sun intensity levels (200 Wm^{-2}). Because some species are known to exhibit a midday stomatal closure we tested several species for this phenomenon. Four species were initially examined: black spruce, _Smilacina_ _trifolia_, leatherleaf, and Labrador Tea. Smilacina and black spruce were dropped from further consideration. Smilacina was dropped because its' growth habit near the ground precluded easy measurement. Black spruce needles presented a methodological problem in determining needle area. We selected new leaves of both ericaceous species growing on healthy plants. Leaves were measured while still attached to the stem. Measurements usually took 30 seconds for each leaf. We were also able to simultaneously measure air temperature, leaf temperature, and sunlight.

To determine whether variation in sunlight would restrict our measurements to a particular time of the day, we measured the stomatal resistance of current year leatherleaf leaves over a range of light intensity (100-1500 microeinsteins m^{-2} sec^{-1}) - in the photosynthetically active zone (PAR). We found higher levels of stomatal resistance did occur at lower light levels (Fig 4.32). However, there was a wide range of stomatal resistance readings at all light levels. Our August, 1985 measurements showed similar results, low stomatal resistance values associated

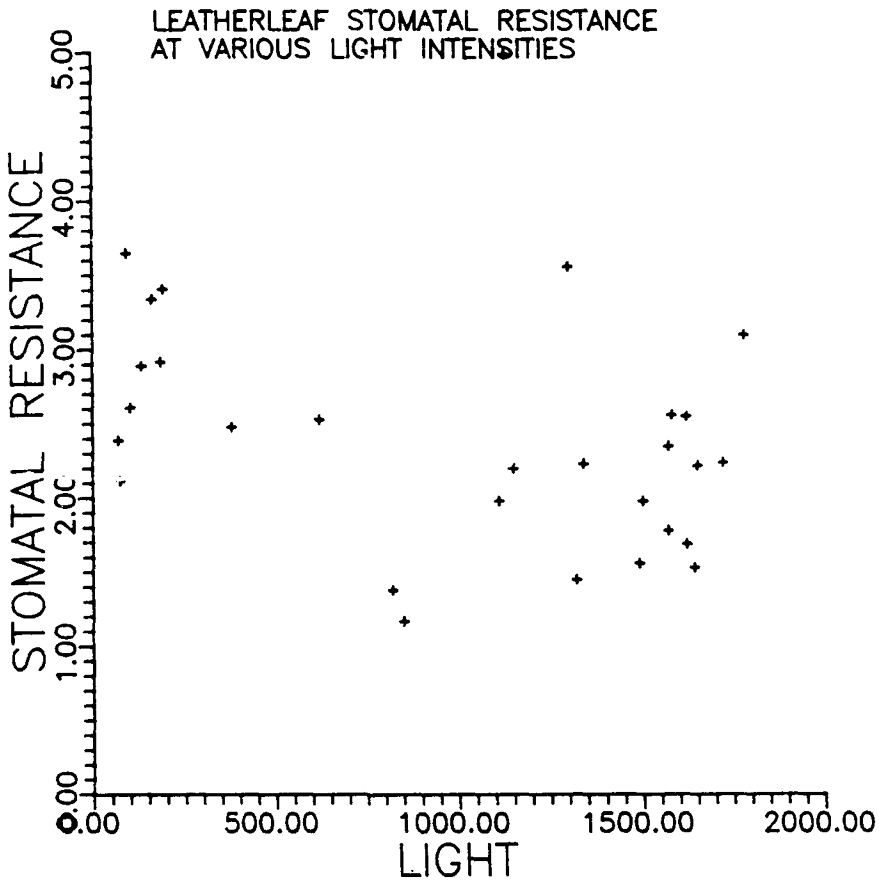
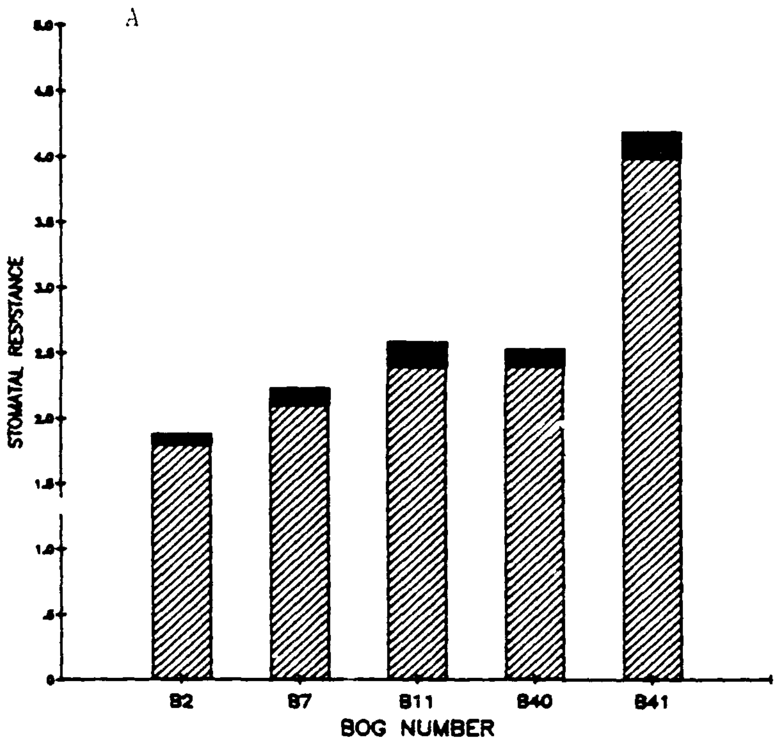


Figure 4.32. Leatherleaf stomatal resistance measurements (s/cm) over a range of light intensities (microeinsteins/cm^2/s.



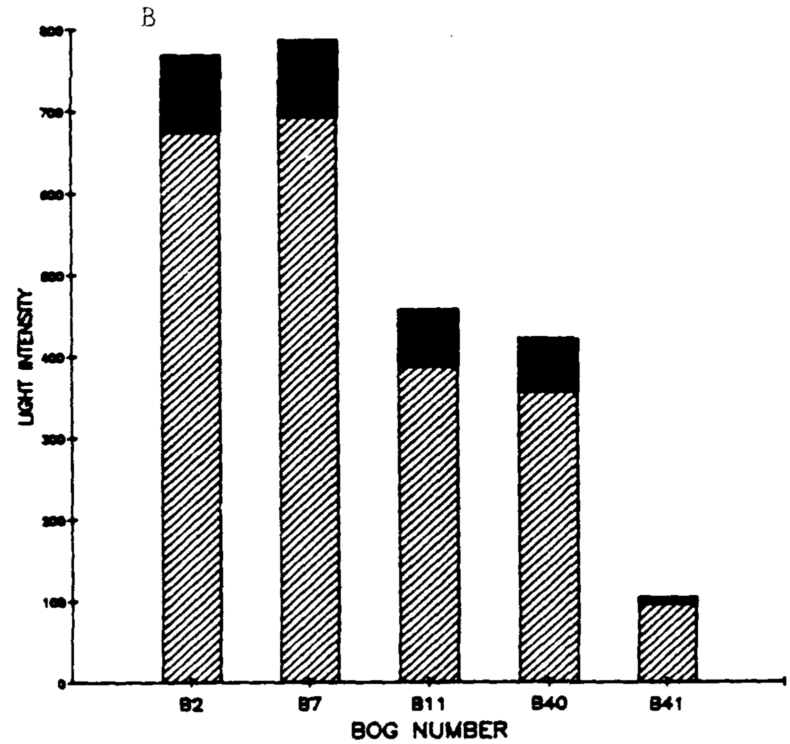


Figure 4.33. A) Mean (- 1 S.E.) stomatal resistance (s/cm) of current-year leatherleaf leaves in 5 bogs surrounding the WTF in Aug., 1985.
B) Mean (- 1 S.E.) light intensity ($uE/cm^2/s$) values for the same bogs when the stomatal resistance was measured.

with low light intensities (values below 400 microeinsteins $m^{-2}sec^{-1}$ (Fig. 4.33). However, we did notice higher stomatal resistance values when light intensity fell below 200 $m^{-2}sec^{-1}$.

We also measured stomatal resistance in ten individual leatherleaf and Labrador Tea plants several times one day at one site. There was no midday stomatal closure (Fig.4.34a,b). Readings of stomatal resistance were consistent from 0930 to 1530 hours despite changes in light levels (Fig. 4.35a,b). Other variables also correlated with light and time of day such as leaf temperature and air temperature did not seem to influence stomatal resistance (Fig. 4.36a,b). Because the response of leatherleaf and Labrador Tea stomatal resistance was similar at moderate to high light levels, we measured stomatal resistance of Labrador Tea leaves over a range of light levels from <100 to >1500 microeinsteins $m^{-2}sec^{-1}$). There was no pronounced increase of stomatal resistance at low light levels unlike the leatherleaf results.

Leatherleaf more typically grows in the open and is not shade tolerant. Labrador Tea is more typically found in partially shaded habitats is more tolerant than leatherleaf to low light levels. We selected Labrador tea as our test species since it did not exhibit a tendency to close its stomates at lower light intensities.

We measured stomatal resistance on sunny days when light intensity in the open was greater than 400 microeinsteins $m^{-2}sec^{-1}$. Only current-year, fully expanded, attached leaves were measured. With each diffusive resistance reading we also measured

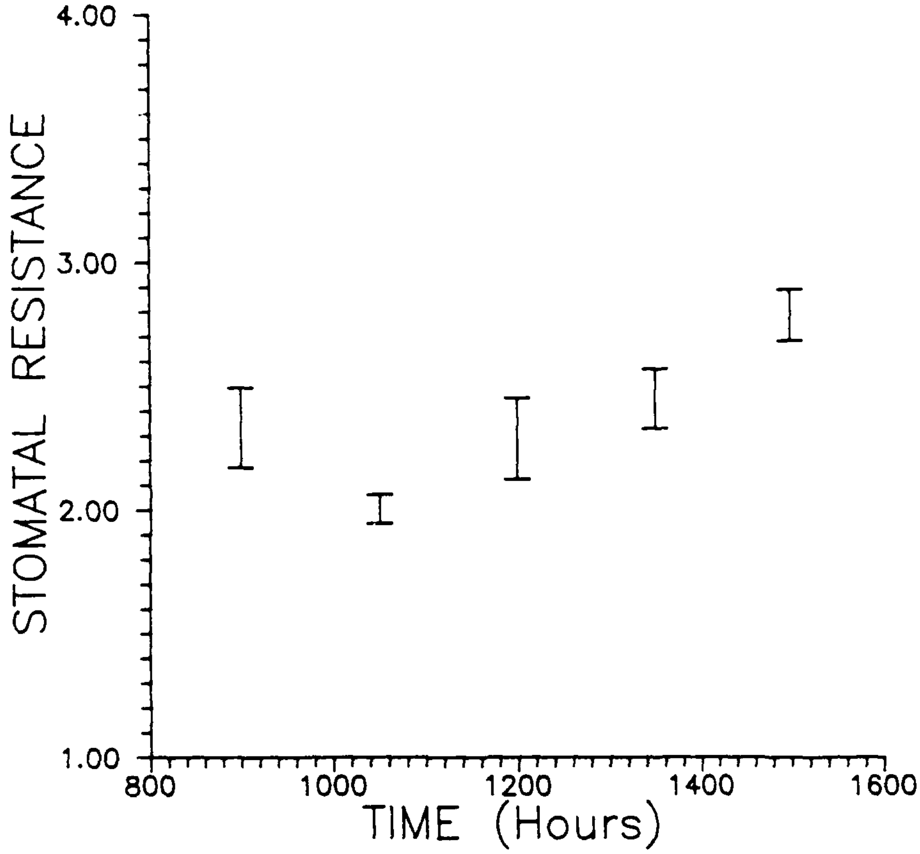


Figure 4.34a. Mean (± 1 S.E.) stomatal resistance (s/cm) measurements from 10 Labrador Tea plants, taken over the course of one day.

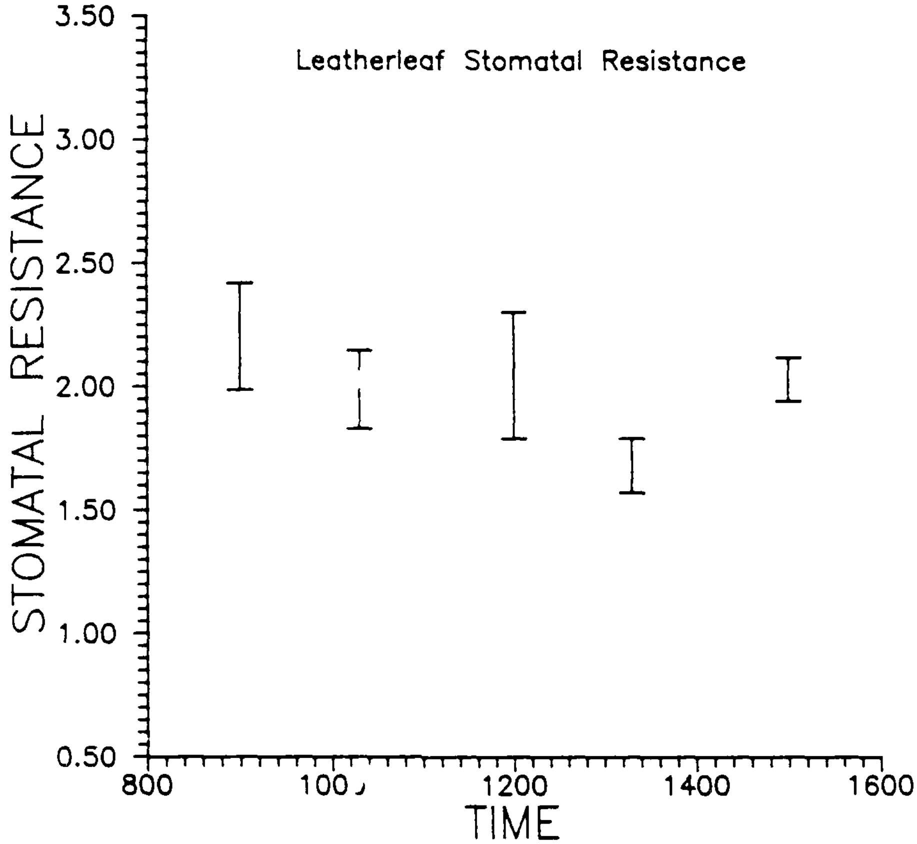


Figure 4.34b. Mean (± 1 S.E.) stomatal resistance (s/cm) measurements from 10 leatherleaf plants taken over the course of one day.

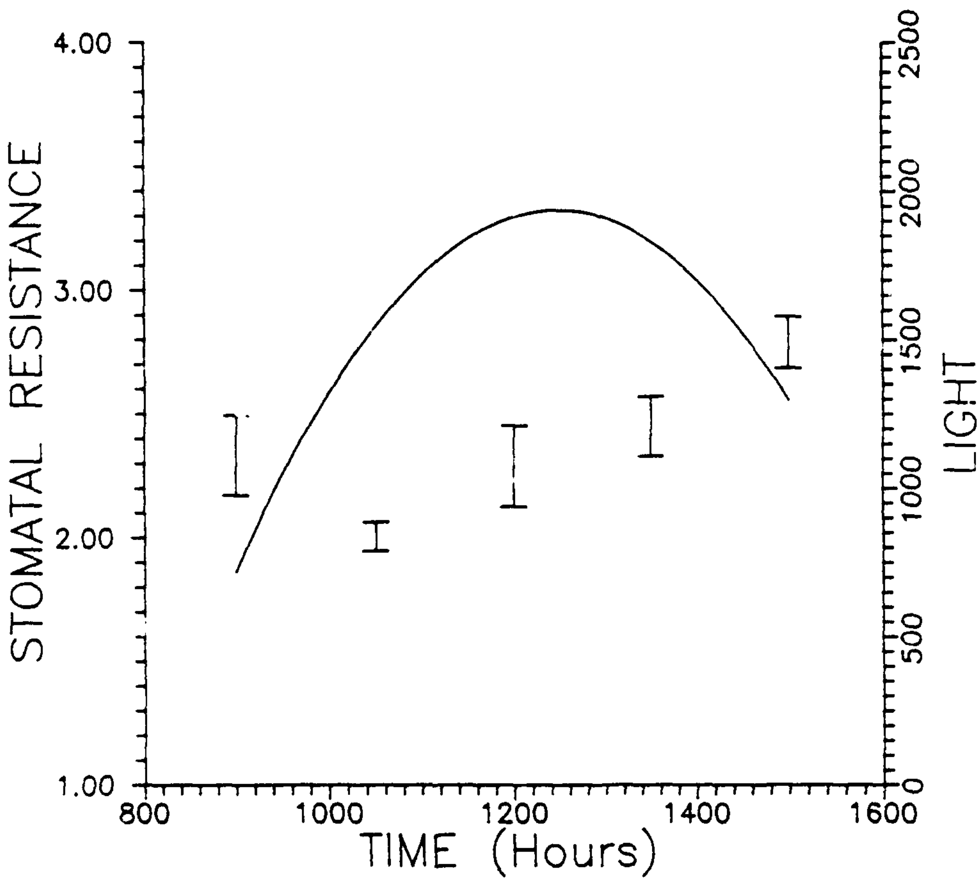


Figure 4.35a. Mean ($\pm$ 1 S.E.) stomatal resistance measurements (s/cm) from 10 Labrador Tea plants and the change in light intensity (smoothed line) (uE/cm^2/s) over the course of one day.

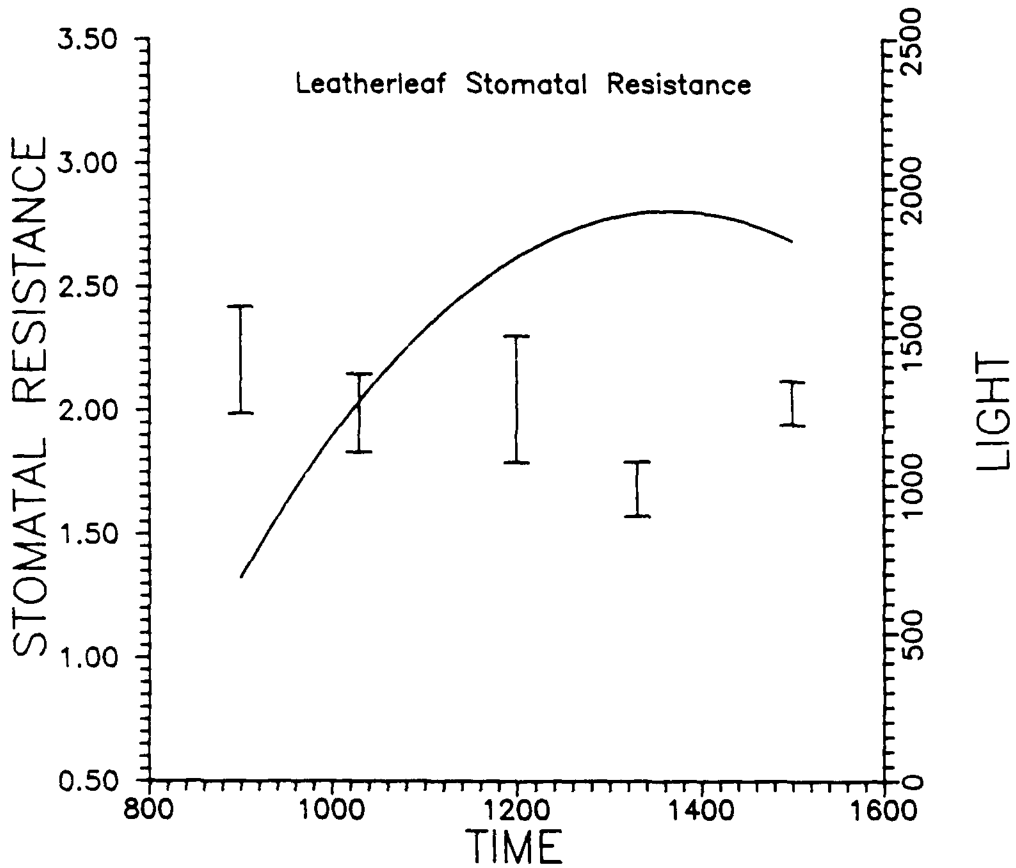


Figure 4.35b. Mean ($\pm$ 1 S.E.) stomatal resistance measurements (·/cm) from 10 leatherleaf plants and the change in light intensity (smoothed line) (uE/cm^2/s) over the course of one day.

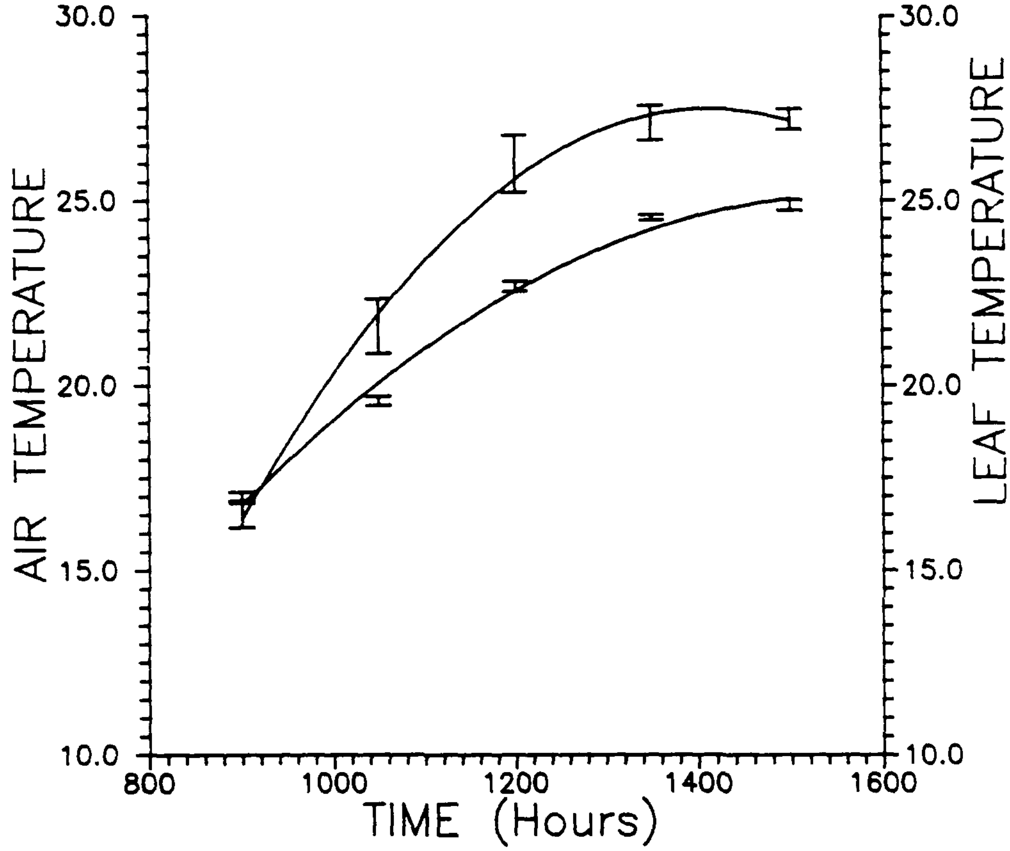


Figure 4.36a. Mean (± 1 S.E.) air temperature (lower curve) and Labrador Tea leaf temperature (°C) (upper curve) measured over the course of one day.

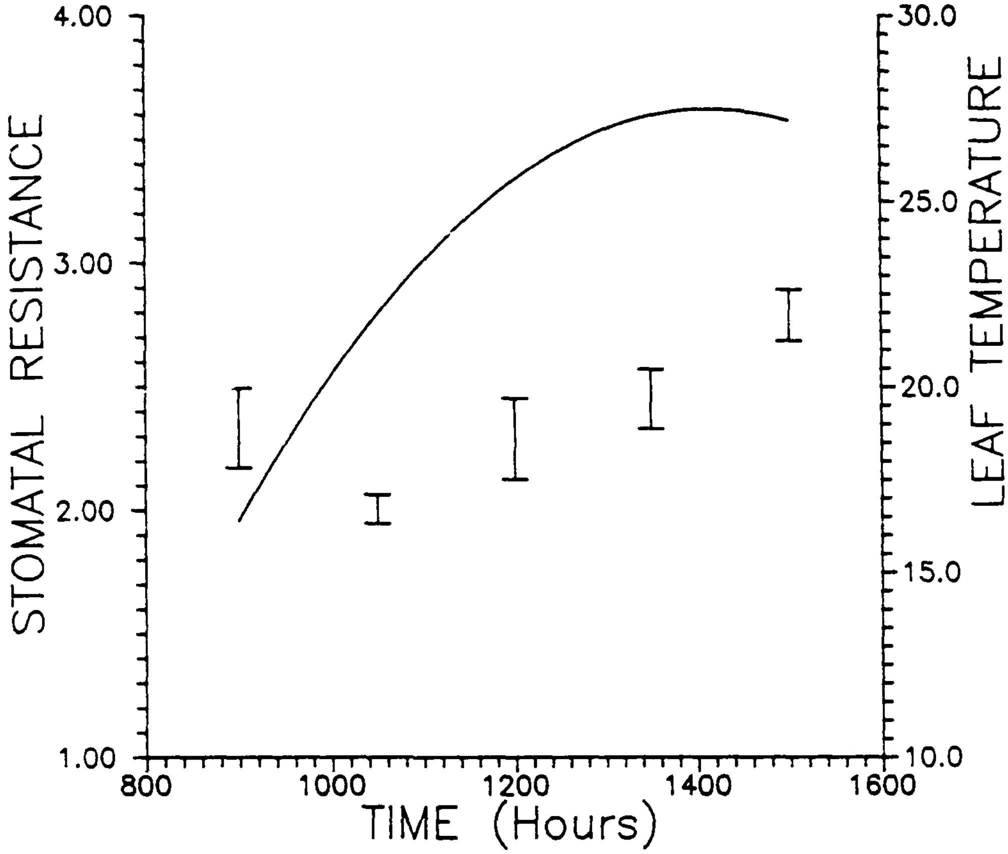


Figure 4.36b. Mean stomatal resistance (sec/cm) and leaf temperature (^{o}C) measured from tem Labrador Tea plants over the course of one day.

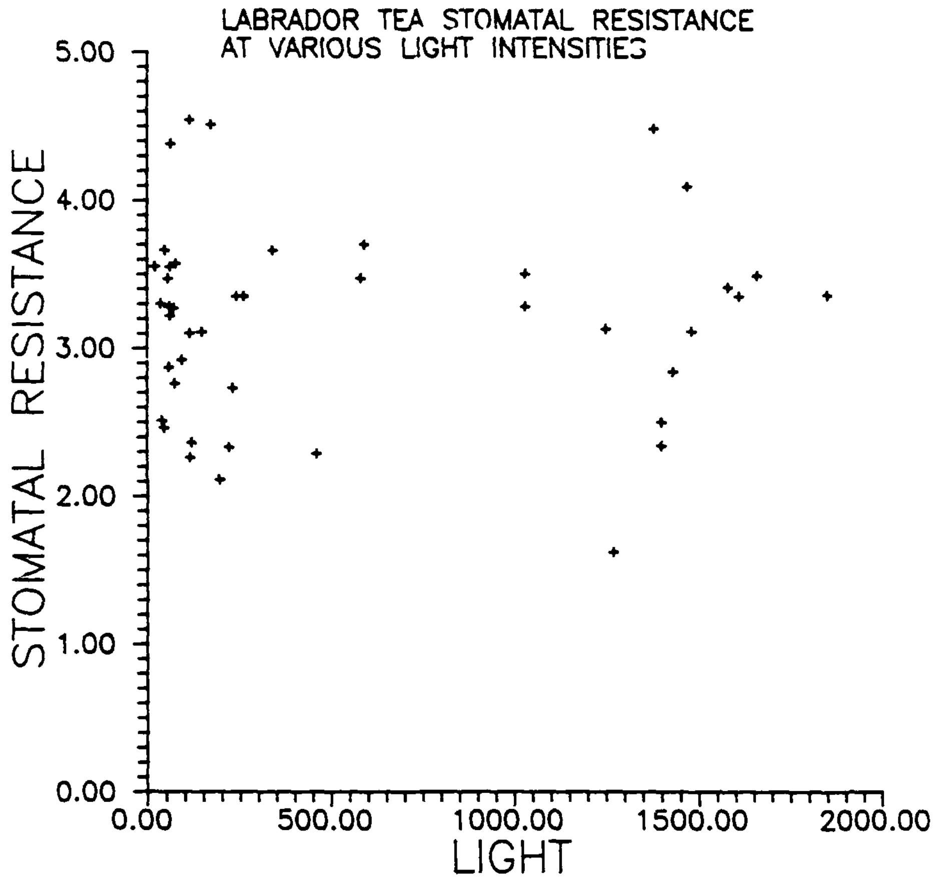


Figure 4.37. stomatal resistance (sec/cm) of current-year Labrador Tea leaves measured over a range of light intensity ($uE/cm^2/s$).

leaf temperature, light intensity, and air temperature. Light readings for leaf measurements differed from the light readings taken in the open. This usually resulted from localized shading from trees or clouds. We ignored these transient effects as long as light levels were not reduced below 100 microeinsteins $m^{-2}sec^{-1}$. Because measurements were made over several days (and environmental parameters usually change somewhat from day to day) we attempted to stratify our measurements by ELF type over the sampling period to cover the range of light variation.

We measured plants at all 11 sites four times; twice in 1986 (July and August) and twice in 1987 (July and August). In 1986, we took measurements of 30 individuals in each of eleven bogs (five samples in each of six plots). In 1987, we doubled the sample size (n=60 per bog/10 samples in each of six plots). We estimated that the increase in sample size in 1987 would allow us to detect 20% differences in means at the 0.05 level of significance with an 80% probability. However, there was a trade-off between the increase in sample size and extending the measurement period. We encountered greater variability in cloud cover, humidity, and temperature in 1987 than 1986. Nonetheless, we attempted to be consistent in measuring stomatal resistance under uniform environmental conditions. We even made repeated measurements in one or two bogs during each sampling period.

Mean monthly values for diffusive resistance and means for associated environmental variables are presented in Figures 4.38-4.42 and Appendix H. Stomatal resistance values were generally uniform, but August 1987 readings are slightly higher. Because environmental conditions varied from one year to the

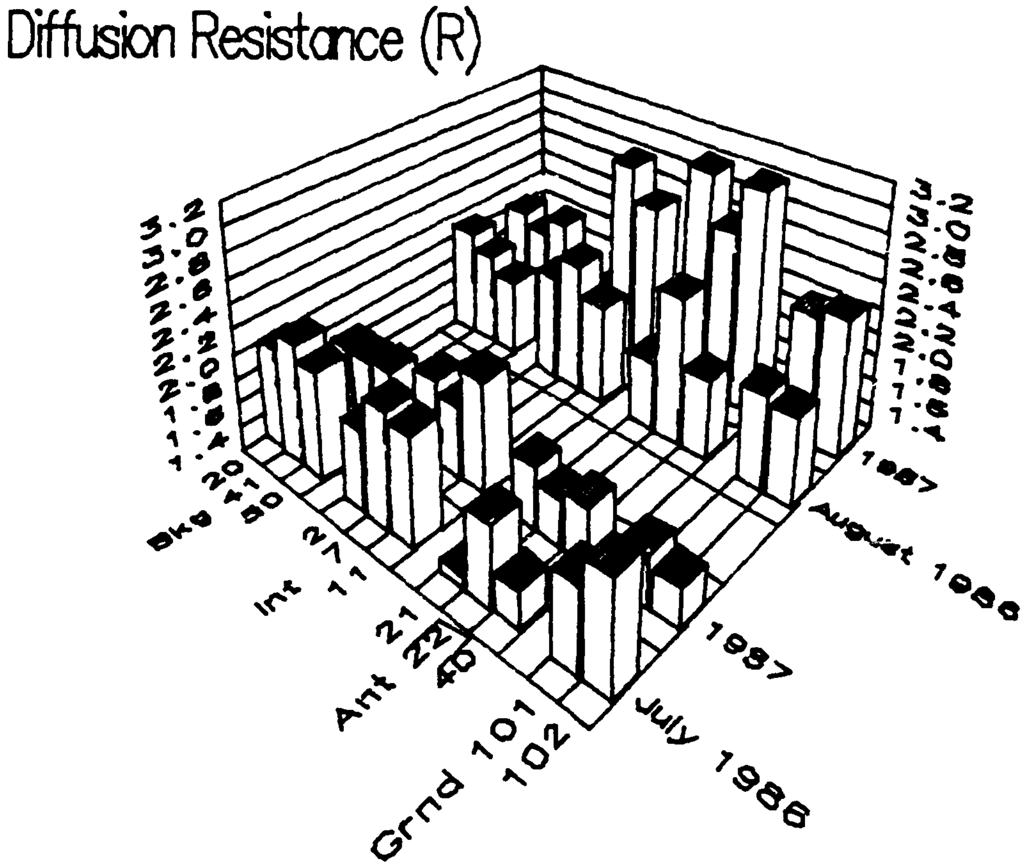


Figure 4.38. A comparison of mean stomatal resistance (s/cm) of current-year leatherleaf leaves in July and August, 1986 and 1987.

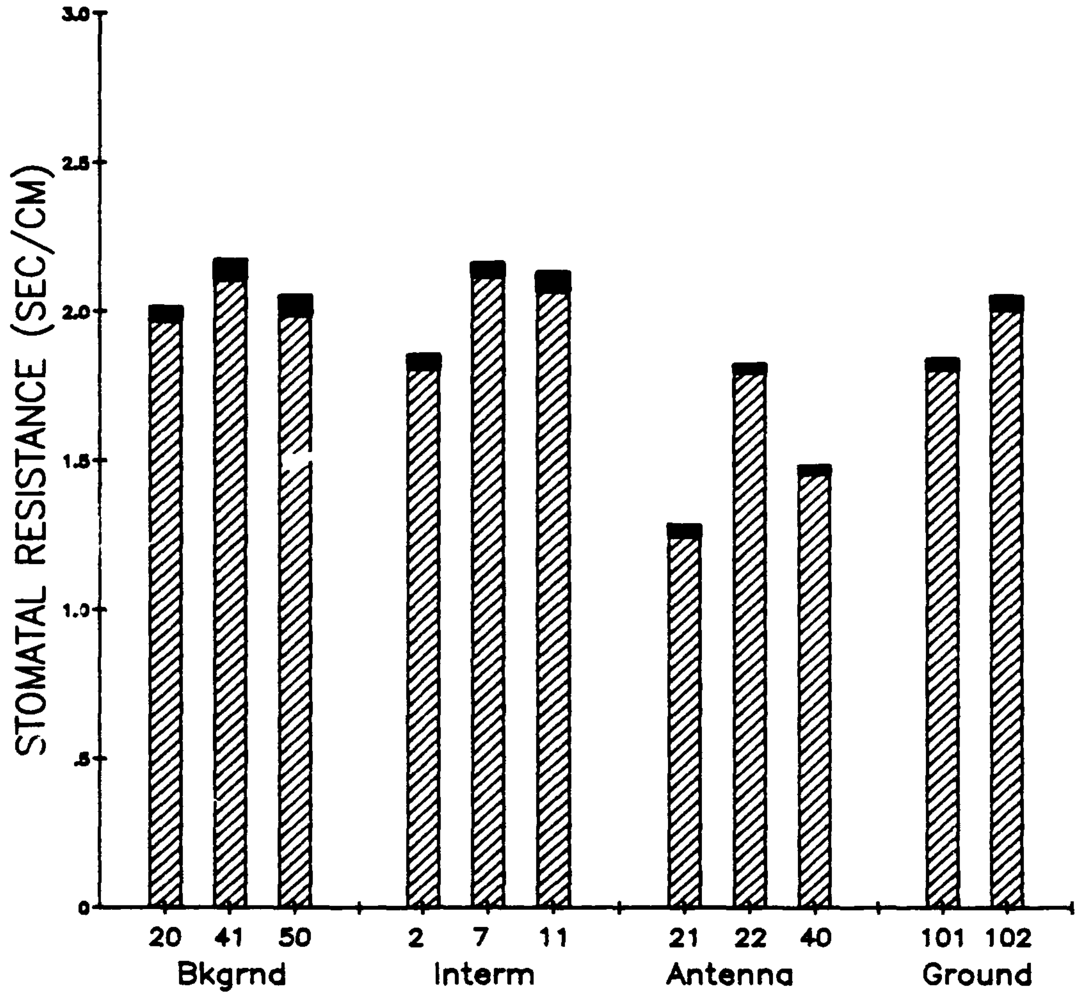


Figure 4.39. Mean (- 1 S.E.) stomatal resistance of current-year Labrador Tea leaves in July, 1986.

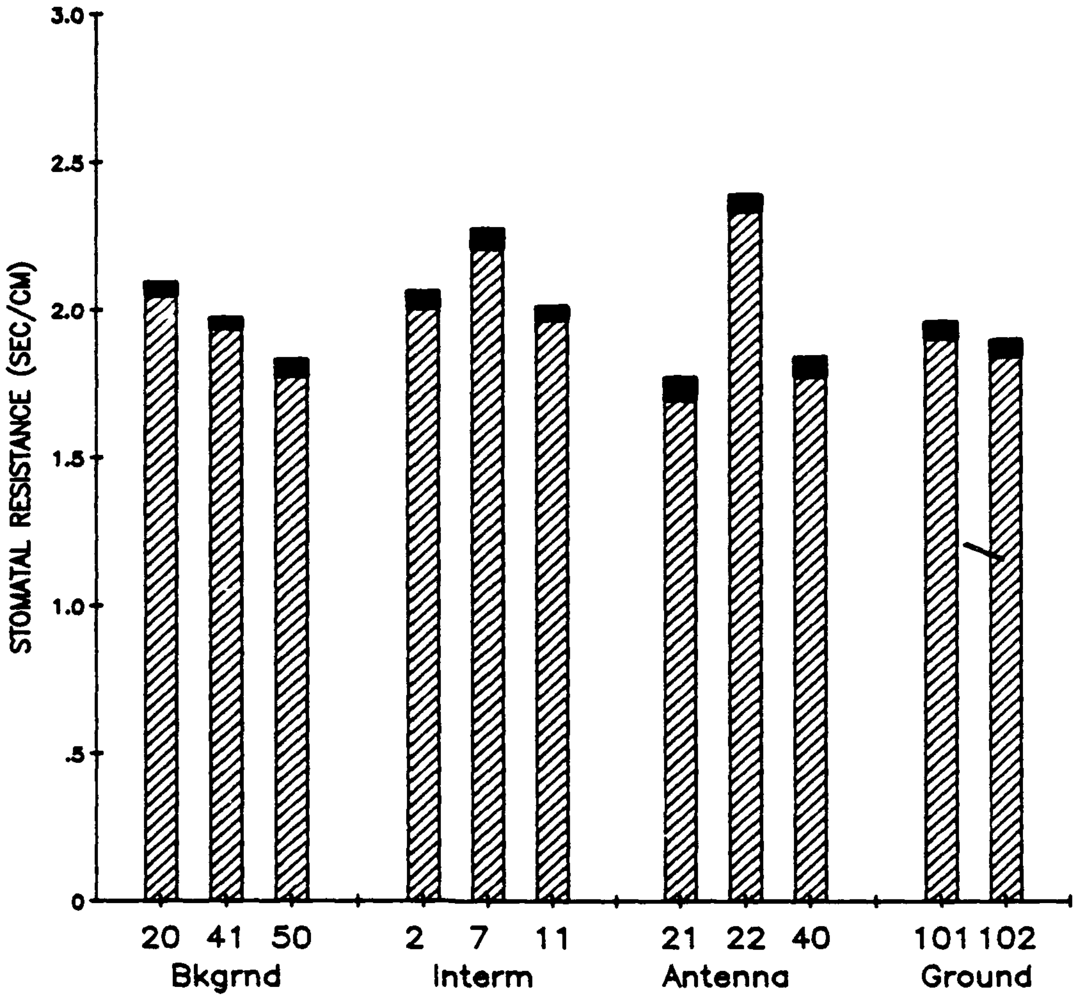


Figure 4.40. Mean (– 1 S.E.) stomatal resistance of current year Labrador Tea leaves in August, 1986.

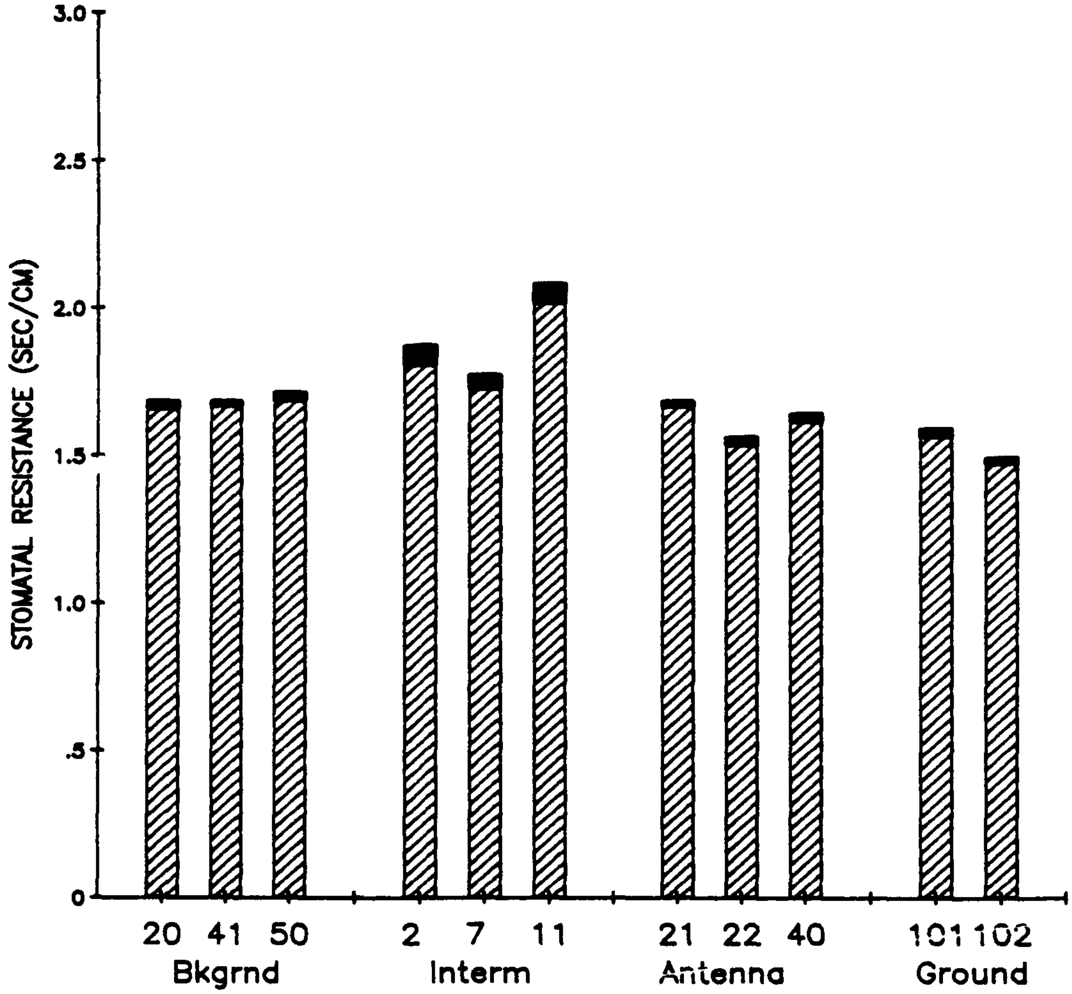


Figure 4.41. Mean (- 1 S.E.) stomatal resistance of current-year Labrador Tea leaves in July, 1987.

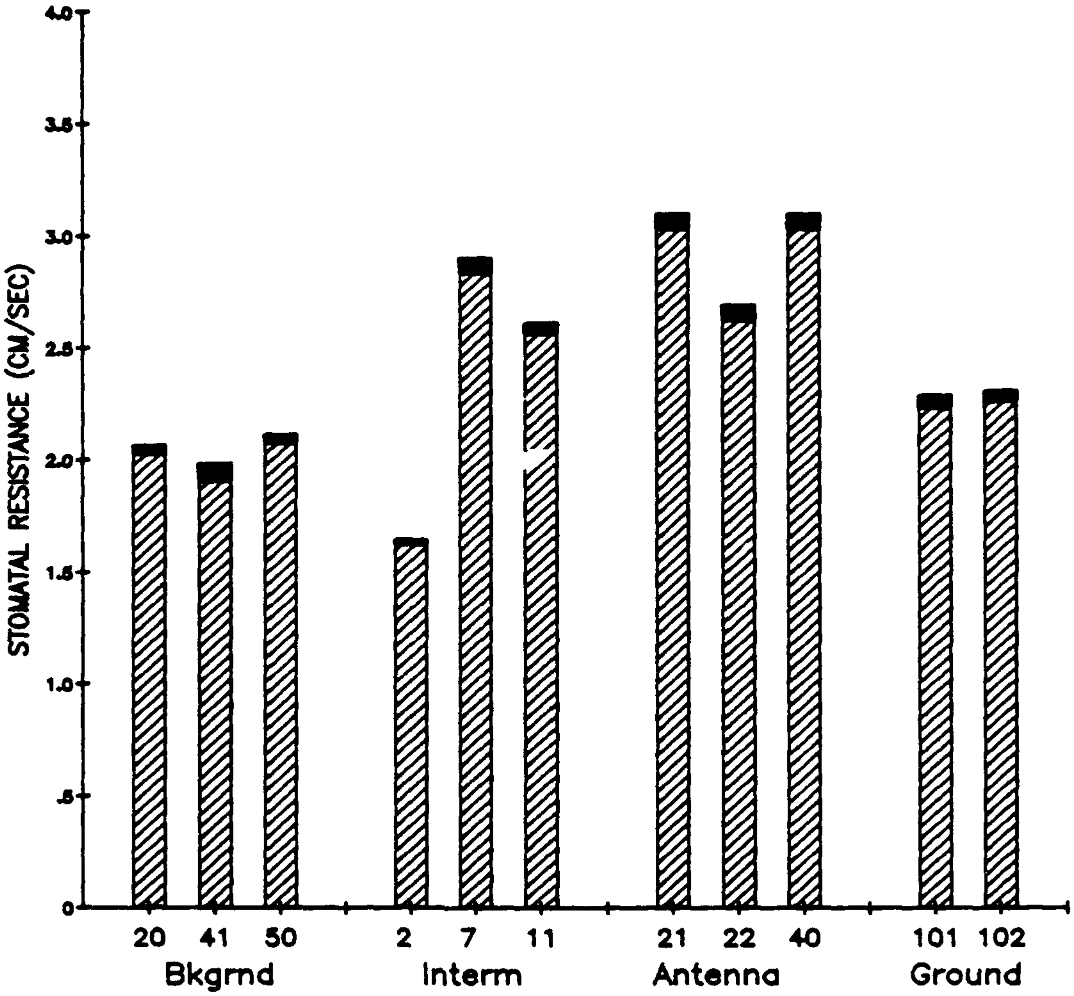


Figure 4.42. Mean (- 1 S.E.) stomatal resistance of current-year Labrador Tea leaves in August, 1987.

next, valid comparisons between years cannot be made. Therefore, we analyzed the four data sets independently using two statistical tests: (1) nested analysis of variance (Table 4.10) and (2) multiple regression (Table 4.11 -4.14).

We used covariates (where appropriate) in the nested anova analysis to take into account changes in environmental conditions from one day to the next during the measuring period. Light intensity was commonly found to meet the requirements for use as a covariate as well as leaf temperature (see Statistical Analysis section). Significant differences ($p<0.05$) in diffussive resistance between levels of ELF exposure were only evident in the July, 1987 data set. However, significant bog and plot differences were found in each data set except for July, 1987.

The results of the multiple regression analysis were contradictory as shown in (Tables 4.11-4.14). The set of independent variables tested in each model included: two water quality principal components (PCA1 and PCA2 representing the statistical summary of the water quality variables for those sampling periods), the principal components associated with the porometer environmental measurements (PRIN1 and PRIN2 representing the statistical summary of the variables measured along with diffusive resistance), the principal component from the ELF fields (ELFSCR), time of day a measurement was taken (TIME), and the potassium content (K) of the foliage in that plot. All data sets were tested for collinearity and ill conditioned data removed according to the criteria set forth in Dillon and Goldstein 1984 (see Statistical Analysis Section for

Table 4.10 Summary of results from the nested analysis of variance for stomatal resistance measurements. F statistics are presented for each level of the design; significance is shown by *** ($p<.0001$), ** ($p<.001$), * ($p<.05$), NS = not significant

Experiment	Treatment (ELF level)	Bog (within treat)	Plot (within bog)
July 1986	3.88 NS	7.36 ***	2.93 ***
August 1986	1.68 NS	3.70 **	2.50 ***
July 1987	4.74 *	1.66 NS	4.17 ***
August 1987	3.14 NS	16.60 ***	2.51 ***

Table 4.11. Results from forward stepwise multiple regression of stomatal resistance of Labrador Tea vs a set of predictor variables (a criterion of 0.15 probability level was used for entrance or removal from the model).

JULY 1986

INDEPENDENT VARIABLE	B	B_{std}	F	Sign.	R^2 partial
PCA2	-.07	-.24	6.08	.017	.04
ELFSCR	-.23	-.72	56.24	.0001	.38
PRIN 1	-.04	.20	3.82	.0554	.03
K	.00006	.18	3.51	.0658	.05
TIME	.0008	-.32	8.82	.0043	.03

Y - INTERCEPT = 2.37

Model Adj. R^2= 0.4822

ANOVA TABLE

SOURCE	df	SS	MS	F	Sign.
REGRESSION	4	2.56	0.64	10.31	.0001
ERROR	61	3.80	0.06		

Table 4.12. Results from forward stepwise multiple regression of stomatal resistance of Labrador Tea vs a set . predictor variables (a criterion of 0.15 probability level was used for entrance or removal from the model).

AUGUST 1986

INDEPENDENT VARIABLE	B	B_{std}	F	Sign.	R^2 partial
PRIN 1	-.078	-.41	13.97	.0004	.17
PRIN 2	-.071	-.27	6.05	.0166	.07

Y - INTERCEPT = 2.02

Model Adj. R^2= 0.22

ANOVA TABLE

SOURCE	df	SS	MS	F	Sign.
REGRESSION	2	1.11	0.56	10.01	.0002
ERROR	63	3.50	0.06		

Table 4.13. Results from forward stepwise multiple regression of stomatal resistance of Labrador Tea vs a set of predictor variables (a criterion of 0.15 probability level was used for entrance or removal from the model).

JULY 1987

INDEPENDENT VARIABLE	B	B_{std}	F	Sign.	R^2 partial
PCA 1	-.043	-.22	4.43	.0394	.05
TIME	-.0002	-.27	5.55	.0217	.19
PRIN 1	-.037	.31	7.66	.0075	.09

Y - INTERCEPT = 1.40

Model Adj. R^2= 0.29

ANOVA TABLE

SOURCE	df	SS	MS	F	Sign.
REGRESSION	3	0.74	0.25	9.66	.0001
ERROR	61	1.55	.03		

Table 4.14. Results from forward stepwise multiple regression of stomatal resistance of Labrador Tea vs a set of predictor variables (a criterion of 0.15 probability level was used for entrance or removal from the model).

AUGUST 1987

INDEPENDENT VARIABLE	B	B_{std}	F	Sign.	R^2 partial
PCA 1	.17	.34	13.56	.0005	.05
PCA 2	-.14	-.28	5.57	.0216	.04
ELFSCR	.39	.77	49.37	.0001	.23
PRIN 1	-.10	-.29	11.31	.0014	.06
PRIN 2	.21	.41	16.57	.0001	.07
TIME	.0010	.46	22.71	.0001	.16

Y - INTERCEPT = 1.28

Model Adj. R^2= 0.56

ANOVA TABLE

SOURCE	df	SS	MS	F	Sign.
REGRESSION	6	9.88	1.65	14.93	.0001
ERROR	59	6.51	0.11		

details). We used a stepwise, forward selection, multiple regression model using a criterion of 0.15 as the significance level for a variable to enter or leave the model.

The overall F-statistic was significant for each of the stepwise regressions indicating that a significant amount of variation in stomatal resistance was explained by the independent variables (R^2 ranged from 0.22 to 0.56). However, the independent predictor variables differed in each model. TIME (3), ELFSCR (2), PRIN1 (4), PRIN2(2), and PCA2(2) were retained in the model more consistently than the other independent variables.

The standardized partial regression coefficients (B_{ST}) indicates the relative importance of the independent variables in determining stomatal resistance (Table 4.11-4.14). In July 1986, ELFSCR had a high positive influence on stomatal resistance but had a relatively high negative influence on diffusive resistance in August 1987.

DISCUSSION

Nested analysis of variance results from July, 1987 indicated a significant treatment effect (TYPE, levels of ELF/emf exposure). However, no ELF independent variable was significant in the multiple regression model for that month. TIME (time of day measurements were taken) and PRIN1 (a function of sunlight and leaf temperature) were included in the model.

It is possible that bias in our sampling scheme may have influenced the results of the nested anova analysis. We had attempted to stratify our measurements (by not sampling all replicate sites for one treatment type on the same day) to take into account variation in environmental conditions during our

sampling period. Likewise, we sampled under a narrow set of environmental conditions which earlier experiments indicated would give us similar conditions for stomatal response.

We re-examined our sampling methodology for July 1987 paying particular attention to the time of day that measurements were made (Fig. 4.43). We spent approximately one hour in each bog taking stomatal resistance measurements. Once we entered a bog we stayed until all plots were sampled. We constructed a frequency distribution for bog and plots for the daylight hours sampled in July, 1987 and used a G-test (Sokal and Rohlf 1984) to test the hypothesis that the stomatal resistance measurements for the various ELF field types were independent of time of day (Table 4.15). Daylight hours were broken down into two hour segments from 9:00am to 5:00pm. Although we could not reject the null hypothesis when using the eleven sampling periods associated with bogs, when we used the frequency distribution for the 66 plots we found significant dependence for measuring plots of a particular ELF type on the time of day suggesting that we may have inadvertently biased our results.

The results of the multiple regression models are contradictory. Different independent variables were selected in each of the four multiple regressions. We cannot assume that the independent variables chosen in each model represent the most important set of variables to predict stomatal resistance. Stepwise regression only chooses a set of independent variables that **adequately** predicts variation in stomatal resistance. There may also be other variables which we did not measure that could

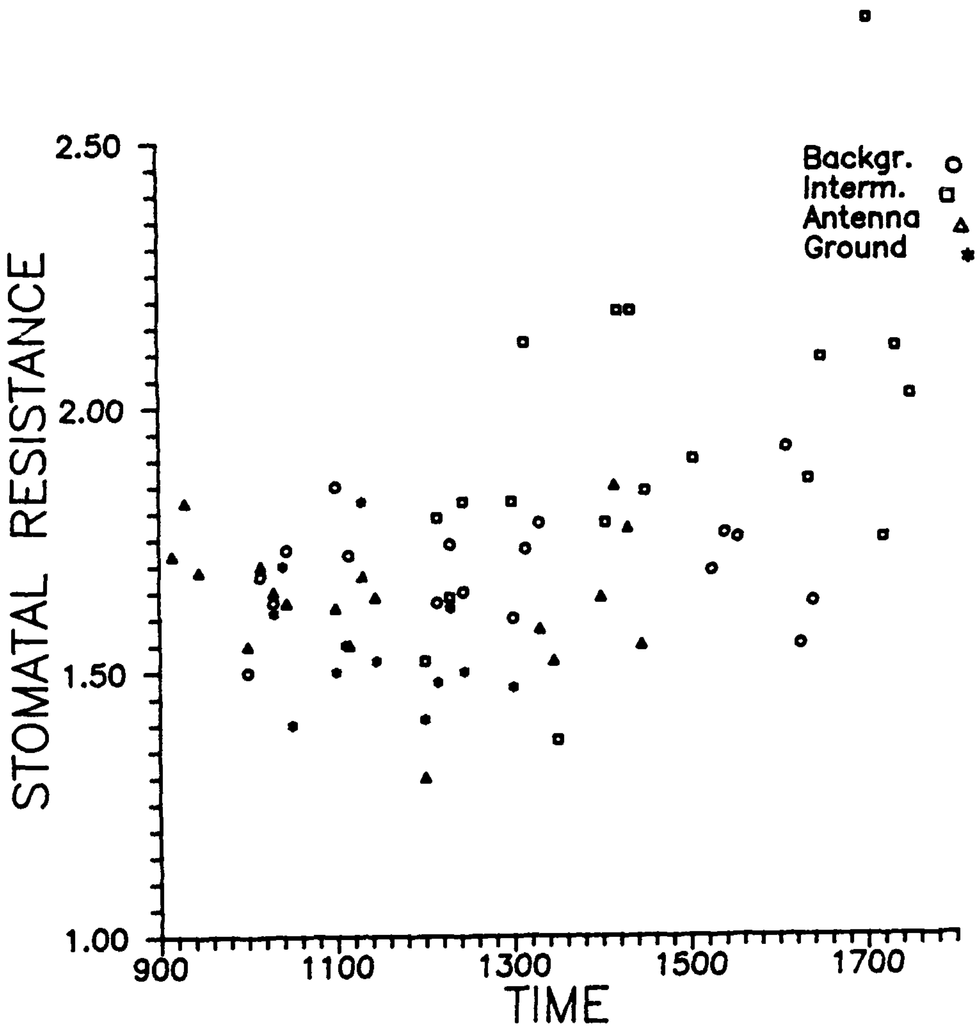


Figure 4.43. Plot means of Labrador Tea stomatal resistance (s/cm) from July, 1987, and the time of day that measurements were made.

Table 4.15. The frequency distribution of the time of day that stomatal resistance sampling occurred (A 4x4 test of independence using the G-Test).

	TYPE			
TIME INTERVAL	BACK	INT	ANT	GRND
0900 - 1100	1	0	1	1
1100 - 1300	1	1	2	1
1300 - 1500	0	1	0	0
1500 - 1700	1	1	0	0

X^2=16.919 a=.05 G=7.52 df=9

	TYPE			
TIME	BACK	INT	ANT	GRND
0900 - 1100	6	0	6	6
1100 - 1300	6	6	12	6
1300 - 1500	0	6	0	0
1500 - 1700	6	6	0	0

X^2=16.919 a=.05 df=9 G=45.1202 *

* significant at p<.05

have a significant impact on the regression. We must interpret the results of these multiple regressions with care.

Since the contradictory results of the multiple regressions have no logical explanation and since they do not correspond to the results of the nested ANOVA's, we conclude that there is no biologically significant stomatal response to ELF electromagnetic field exposure and that other factors must be considered in interpreting our results.

FOLIAR NUTRIENTS

Native plant species in northern bogs are well adapted to a relatively nutrient poor environment. Persistence in these habitats has led to the evolution of distinct traits. For instance, leatherleaf (Chamaedaphne calyculata) and labrador tea (Ledum groenlandicum), both evergreens, have leaf life spans of two or more years. Spruce (Picea mariana) needles remain on the tree for several years before senescing. Smilacina trifolia a herbaceous perennial is capable of resorption of foliar nutrients from old leaves and translocation to new leaves.

Mineral nutrients are active constituents of a number of important plant biochemical pathways. Changes in nutrient status may result in effects ranging from deficiency to toxicity. Variation in plant nutrient levels may lead to plant stress or reduced growth; thereby, impairing the ability of these plants to compete successfully with other species. This in turn may result in shifts in plant species composition and concomitant changes in the biogeochemical cycling in these bog ecosystems.

Although the nutrient status of a plant is often controlled by nutrient availability, plant water stress or other environmental features may also be important. We are interested in determining whether differences in foliar nutrient concentration, if any, are attributable to ELF electromagnetic fields. Specifically, our hypothesis is that there are no differences in foliar nutrient concentration along the ELF exposure gradient.

Foliar analysis has been used as an indicator of nutrient stress in agricultural and horticultural studies (van den

Driessche 1974, Swan 1970). Leaf analysis supplies direct information about the nutritional state of the individuals in a population. We chose to analyze current year foliar tissue of plant species representative of the several life forms found in northern bogs.

Our preliminary sampling and analysis was done in 1983 and 1984. During this time, we developed a sampling protocol, determined appropriate sample size, selected appropriate species to use, and developed nutrient analysis procedures.

The initial species selection included: an ericaceous shrub- leatherleaf (Chamaedaphne calyculata), a herb - Smilacina trifolia, two sedges - Carex oligosperma and Eriophorum spissum, and a tree - black spruce (Picea mariana). In 1985, we decided that, because of limited population size, the two sedges would not be adequate for destructive sampling through 1987. Because Labrador tea (Ledum groenlandicum), another ericaceous shrub, was abundant in all our sites we substituted it for the sedges. We examined the results of a preliminary sampling in 1985 and included it in our sampling program in 1986.

Because nutrient use and uptake and utilization may vary seasonally and the pattern of nutrient accumulation may differ, we collected foliar samples several times during the growing season. Each of the species we studied has its own unique pattern of phenological development; therefore, the specific time of sampling varied. For example, Smilacina initiates its' growth early in the year and senesces by late August. It was sampled earlier than the ericaceous shrubs. Leatherleaf and Labrador tea

flower early in the growing season but do not initiate significant leaf expansion until mid-June. Leaf production and growth continue through the early fall. Black spruce was only sampled once each year. We found that the spruce trees selected for sampling were too small to tolerate repeated destructive sampling. We collected samples during the fall because Swan (1970) suggested that fall samples are best to evaluate the nutrient status of black spruce. During 1983 and 1984 we sampled from marked trees. We later remarked those trees to incorporate them into a permanent sampling protocol in 1985. In 1986, we increased our sample size from 24 to 36 individuals per site to increase the power of our analysis.

We increased our sample size for each species studied several times to improve the power of our statistical analysis. By 1985 we were collecting 36 replicate samples for each species in each site. Six samples were collected from each of the subplots in each of the eleven sampling sites for a total of 396 samples per species per sampling date. In 1987, we decided to collect 120 samples for each species in each site, but to sample each species only once. Foliar tissue samples were collected when a species had reached its' physiological peak as determined by maximum leaf expansion. We did not increase the sample size of spruce. because all appropriately sized trees had already been selected, and increasing the sample size of spruce would have meant collecting from a large number of trees outside our sampling area.

Only current-year foliar tissue was collected from each species. Each replicate sample was large enough to yield at least

0.5 grams of oven-dried leaf material. Following collection and oven-drying, each sample was prepared for analysis by digestion in a sulfuric acid - hydrogen peroxide mixture to oxidize the organic material (van Lietrop 1976). Digested samples were analyzed for three cations: calcium, magnesium, and potassium by atomic absorption spectroscopy. Samples collected in 1987 were analyzed at the UW-Madison Soils and Forage Laboratory by Inductively Coupled Plasma Spectroscopy (ICP). In addition to the three cations, these samples were also analyzed for phosphorus and manganese. For quality control purposes, National Bureau of Standard samples were processed using the same procedure and analyzed for nutrients with satisfactory results (Table 4.16). Spikes of known amounts of cation standard solutions were added to both NBS standards and samples for quality control purposes.

RESULTS

Each species had different mean concentrations of specific foliar mineral nutrients (e.g. Figure 4.44 and Appendix I). However, seasonal patterns in nutrient concentration were similar for all the species (Figs. 4.45 - 4.49). Two distinct trends are apparent. Calcium, magnesium, and manganese increased in concentration over the growing season; whereas, phosphorus and potassium decreased in concentration. Figure 4.50 is an example of year-to-year variation in black spruce nutrient concentration. Although there is variation among bogs, there is also yearly variation. The noticeable decrease in 1985 spruce foliar concentrations is most likely caused by a rust infection found on most trees that year. The high magnesium and potassium levels in 1987 may be the result of recovery from this infection.

Table 4.16 A comparison of certified National Bureau of Standards cation concentrations in standard plant material and values obtained with NBS standard plant material digested in a hydrogen peroxide - sulfuric acid mixture and analyzed at the University of Wisconsin-Milwaukee (UWM) by atomic absorption spectroscopy and University of Wisconsin - Madison Soils and Forage Laboratory (UWM-SFL) by Inductively Coupled Plasma Spectroscopy.

	CONCENTRATION (PERCENT DRY WEIGHT)		
	NBS	UWM	UWM-SFL
Calcium	.41±.02	.41±.02	.41±.01
Magnesium	.58±.03	.56±.001	.56±.01
Potassium	.37±.02	.38±.01	.38±.01
Manganese	.0675±.002	N/A	.0671±.002
Phosphorus	.12±.02	N/A	.12±.005

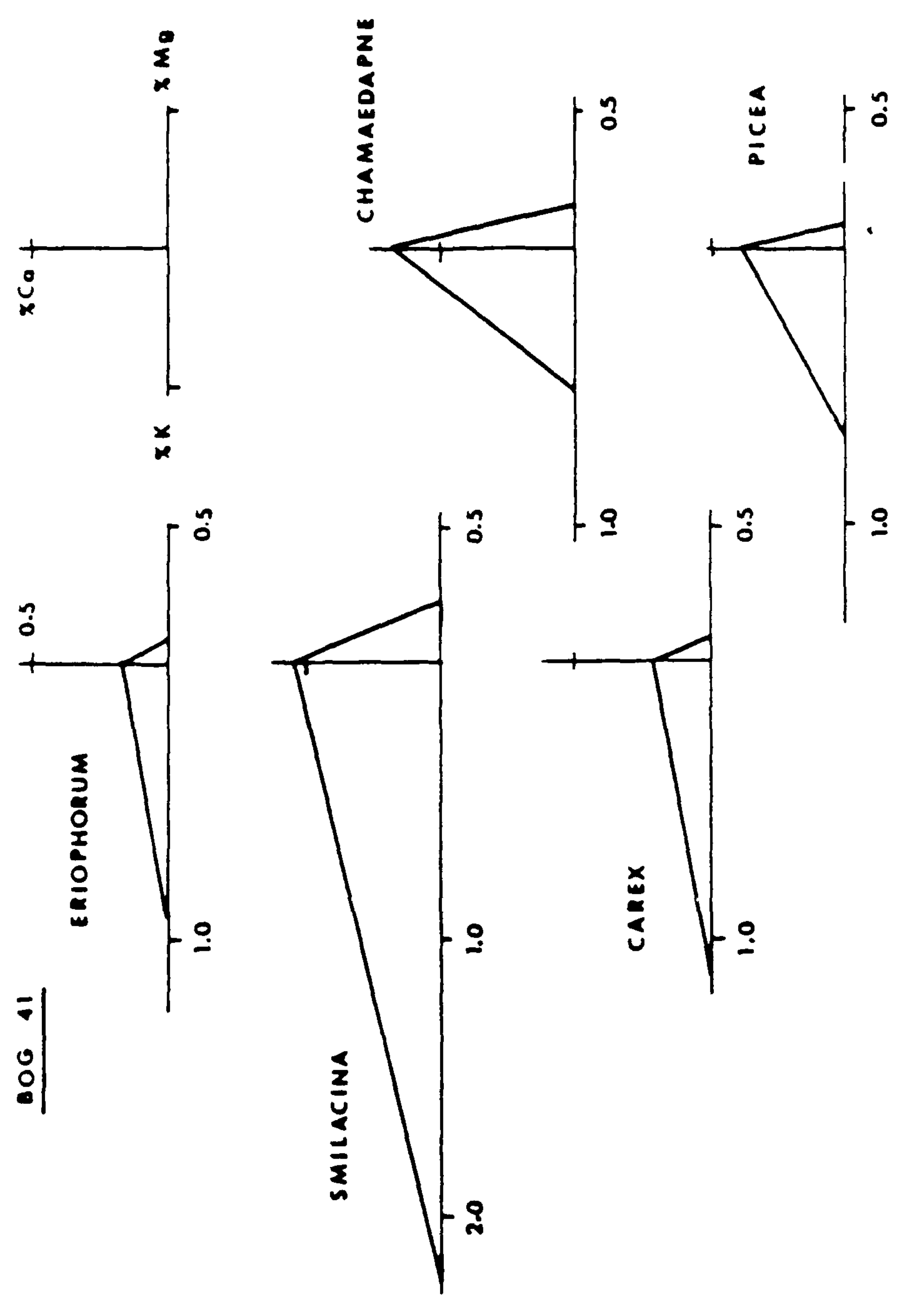


Figure 4.44. The mean nutrient concentration (percent dry weight) for calcium, potassium, and magnesium, determined for replicate samples of 5 species (Chamaedaphne calyculata, Smilacina trifolia, Eriophorum spissum, Carex oligosperma, and Picea mariana) from Bog 41 (Bkg) in August, 1983.

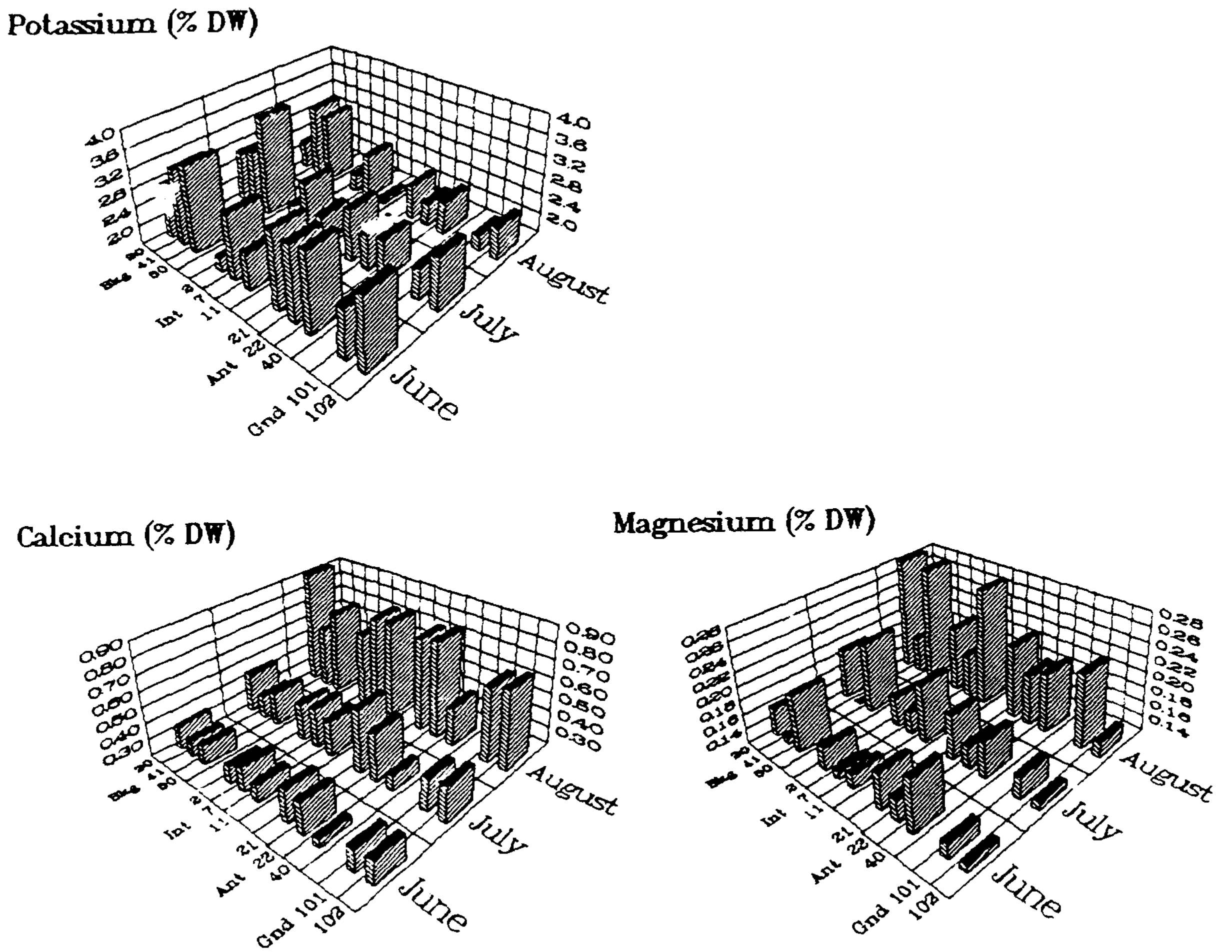


Figure 4.45. Mean nutrient concentrations (percent dry weight) of current-year Smilacina trifolia foliar tissue growing in eleven bogs during 1985.

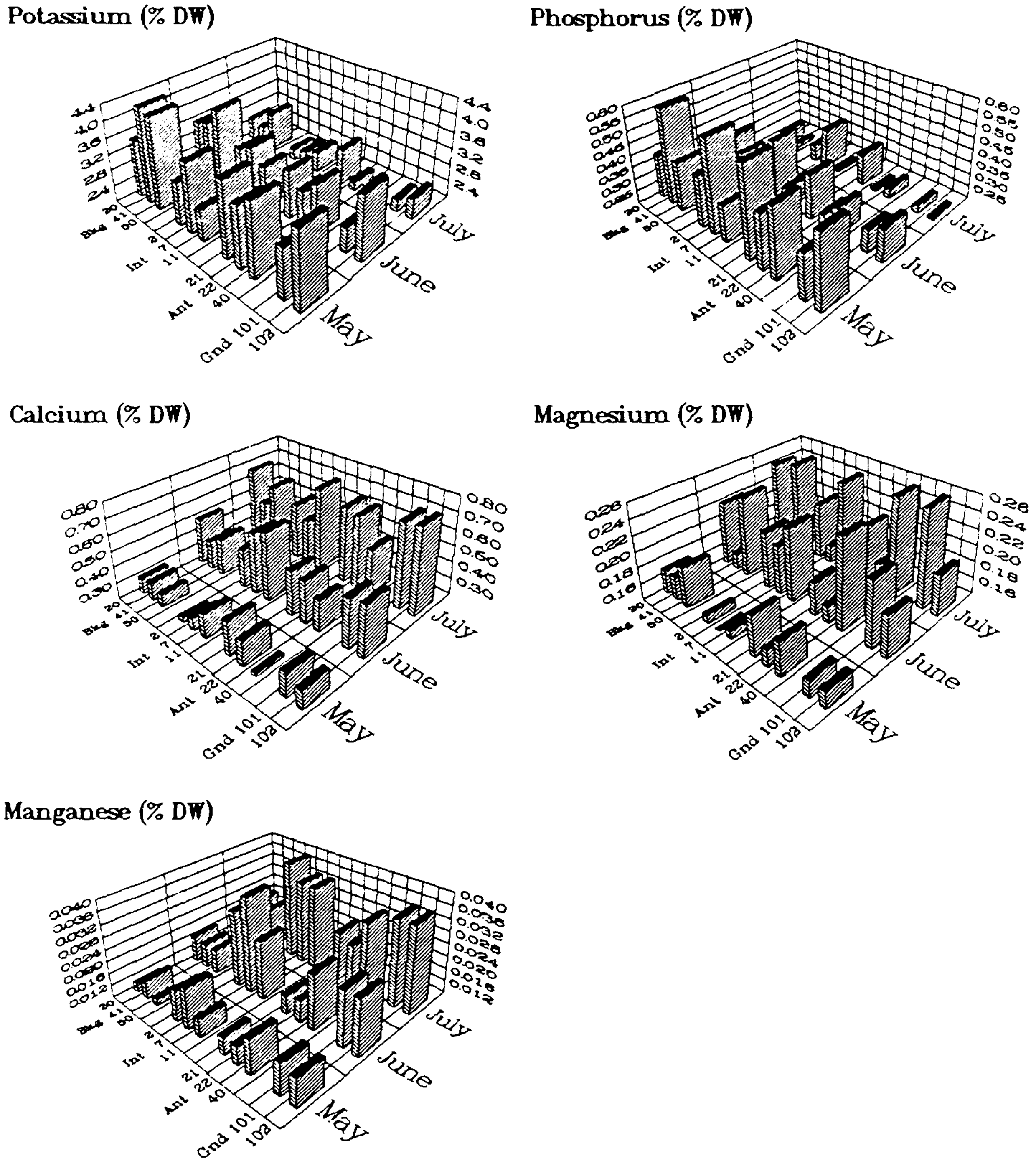


Figure 4.46. Mean nutrient concentrations (percent dry weight) of current-year Smilacina trifolia foliar tissue growing in eleven bogs in 1986.

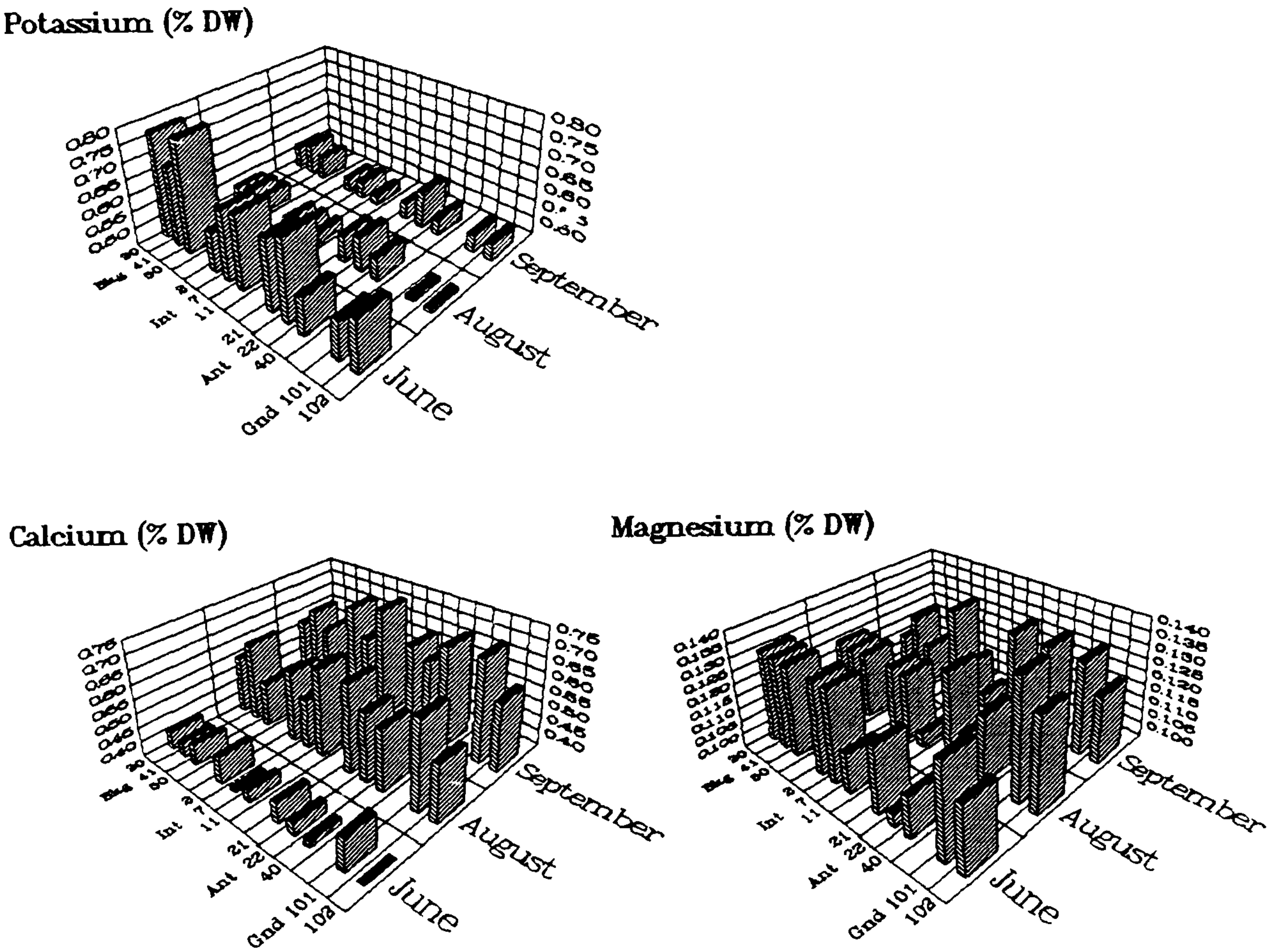


Figure 4.47. Mean nutrient concentration (percent dry weight) of current-year Chamaedaphne calyculata foliar tissue growing in eleven bogs during 1985.

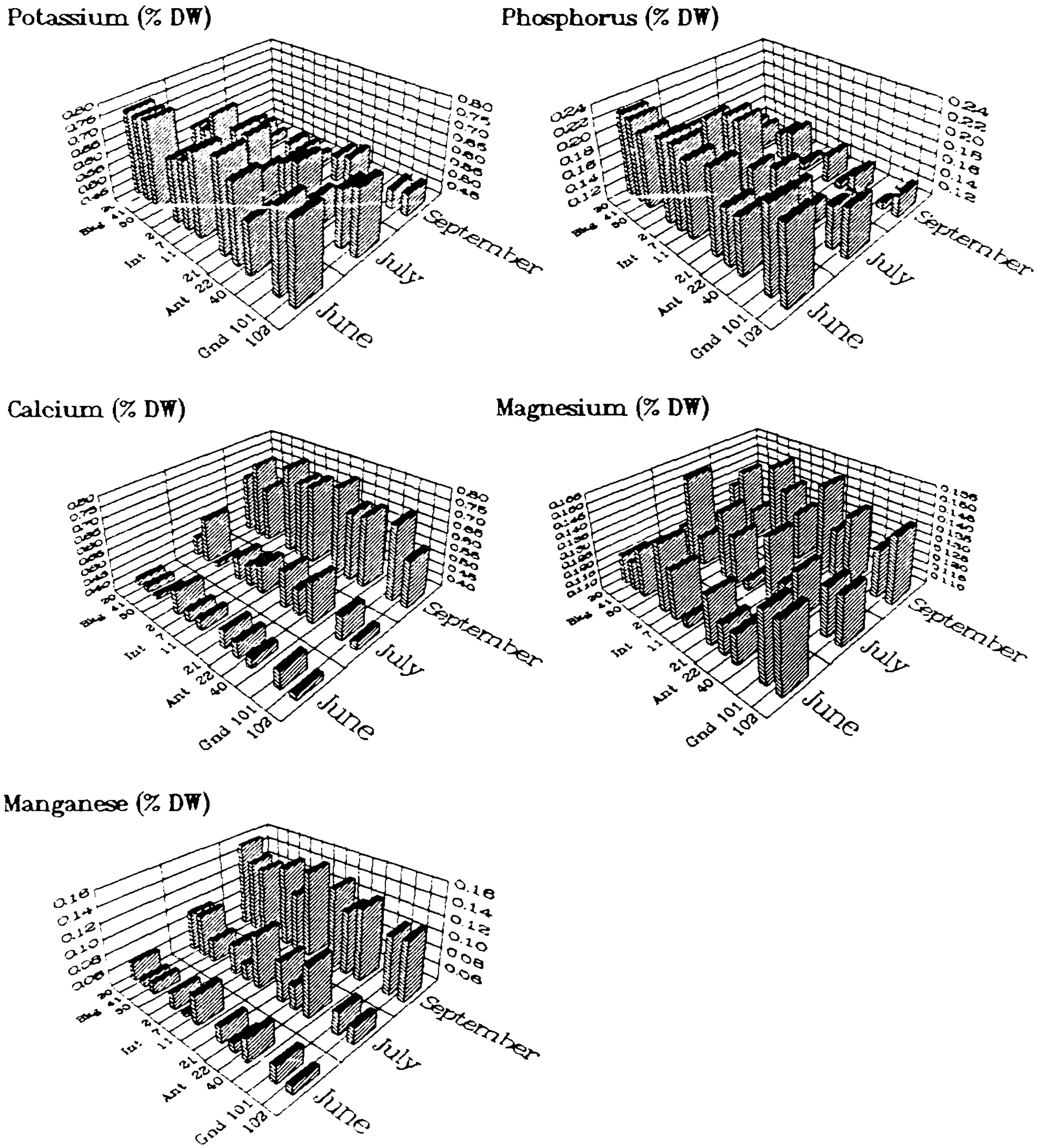


Figure 4.48 Mean nutrient concentration (percent dry weight) of current-year Chamaedaphne calyculata foliar tissue growing in eleven bogs during 1986.

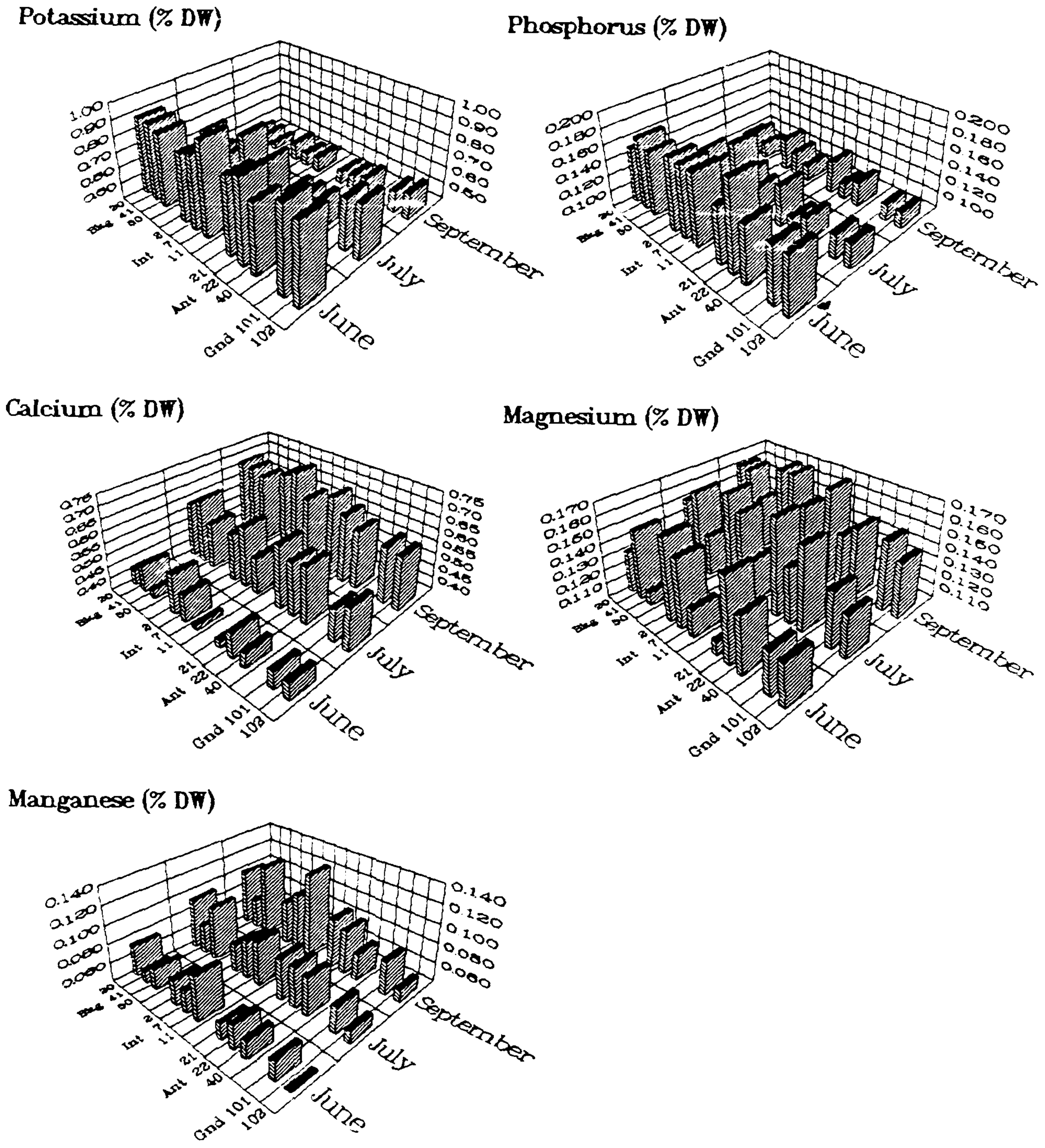


Figure 4.49. Mean nutrient concentration (percent dry weight) of current-year Ledum groenlandicum foliar tissue, growing in eleven bogs during 1985.

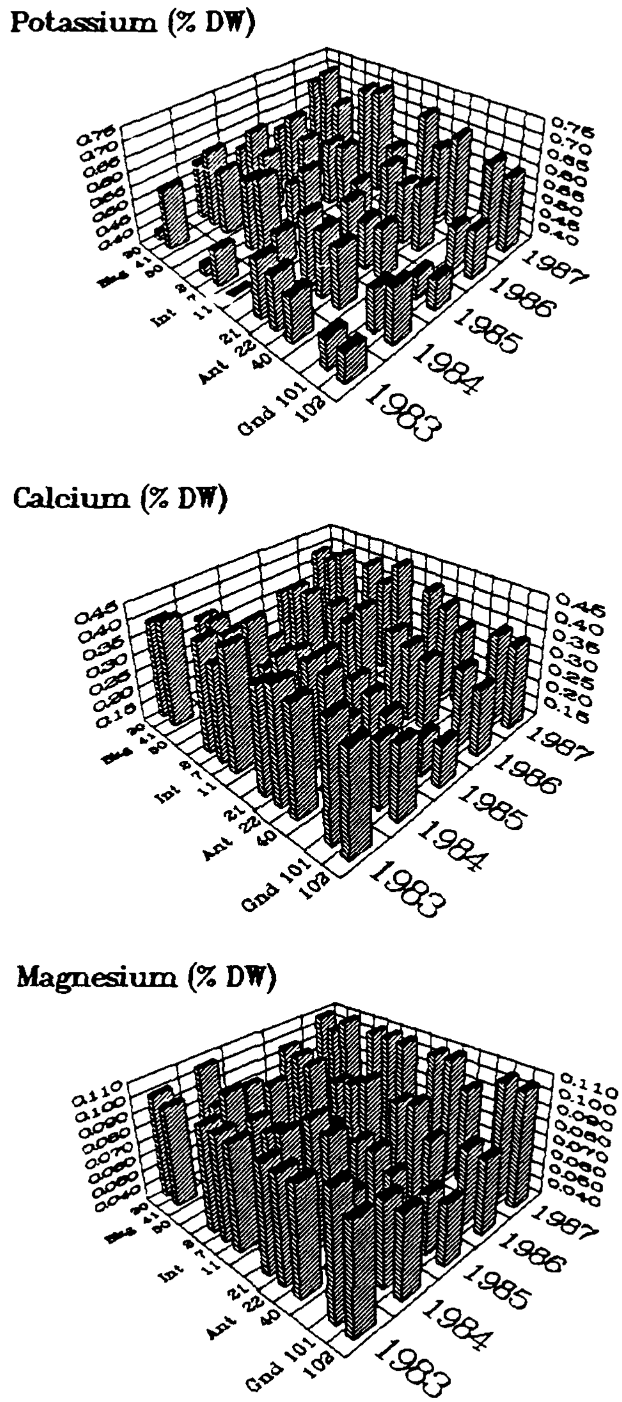


Figure 4.50. Mean nutrient concentrations (percent dry weight) of current-year <u>Picea mariana</u> foliar tissue growing in eleven bogs during 1983 - 1987.

Seventy-nine separate nested ANOVA tests were performed using each individual nutrient for each species at each specific sampling date (Appendix J). Only in five instances were significant treatment effects detected, a frequency no better than that expected by chance alone when using the 5% significance level (Table 4.17 and Figures 4.51 - 4.55). This means that a Type I error (rejecting the null hypothesis when it is, in fact, true) can occur in 5% of the analyses. In almost all other cases, there was a significant bog effect, indicating significant variation in foliar nutrient content among bogs (Appendix J). One pattern that did emerge was related to the manganese content of Smilacina trifolia in 1986. Bkgrnd sites did differ from Interm and Grnd sites in June and July. However this pattern was not observed in May. We cannot evaluate the consistency of these results because manganese was not measured in 1985 and Smilacina was not analyzed in 1987. However, Bkgrnd sites did not differ from Ant sites supporting the hypothesis that there was no ELF effect.

For our multiple regression analyses we used the same environmental components generated by the PCA models for the environmental data set and the principal components associated with the ELF fields as our independent variables (For more details, see the sections on Decomposition and Environmental Analysis). The dependent variables were the mean nutrient concentrations for the plots in each bog (N=66). The amount of variance explained by the multiple regression models was generally low (Table 4.18). Figures 4.56 - 4.60 show the relationship between those cases where the ELF component was

Table 4.17. Summary of the univariate analysis (Nested ANOVA) of tissue nutrient concentrations in species found in peatlands exposed to 76 hz electromagnetic fields produced by the Wisconsin Test Facility. (*) significant treatment effect at $p<0.05$.

	P	K	Ca	Mg	Mn
<u>Smilacina trifolia</u>					
May 1986	-	-	-	*	-
June 1986	-	-	-	-	*
July 1986	-	-	-	-	*
June 1985	n/a	-	-	-	n/a
July 1985	n/a	-	-	-	n/a
August 1985	n/a	-	-	-	n/a
<u>Chamaedaphne calyculata</u>					
June 1986	-	-	-	-	-
July 1986	-	-	-	-	-
September 1986	-	-	-	-	-
June 1985	n/a	-	-	-	n/a
August 1985	n/a	*	-	-	n/a
September 1985	n/a	-	-	-	n/a
<u>Ledum groenlandicum</u>					
June 1986	-	-	-	-	-
July 1986	-	-	-	-	-
September 1986	-	*	-	-	-
September 1987	-	-	-	-	-
<u>Picea mariana</u>					
September 1987	-	-	-	-	-
September 1986	n/a	-	-	-	n/a
September 1985	n/a	-	-	-	n/a

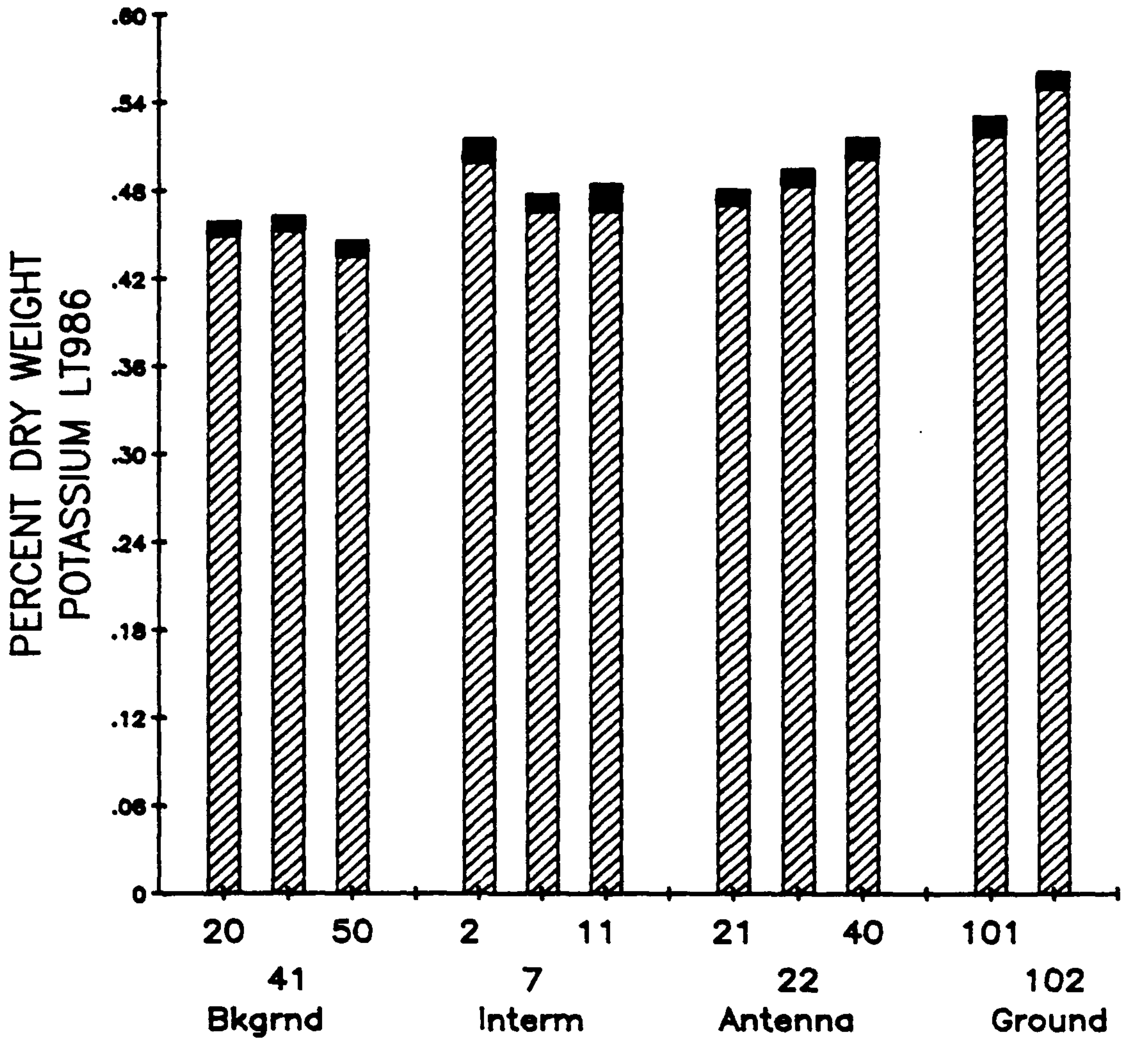


Figure 4.51. Mean (- 1 S.E.) potassium concentration of Ledum groenlandicum foliar tissue from Sept., 1986.

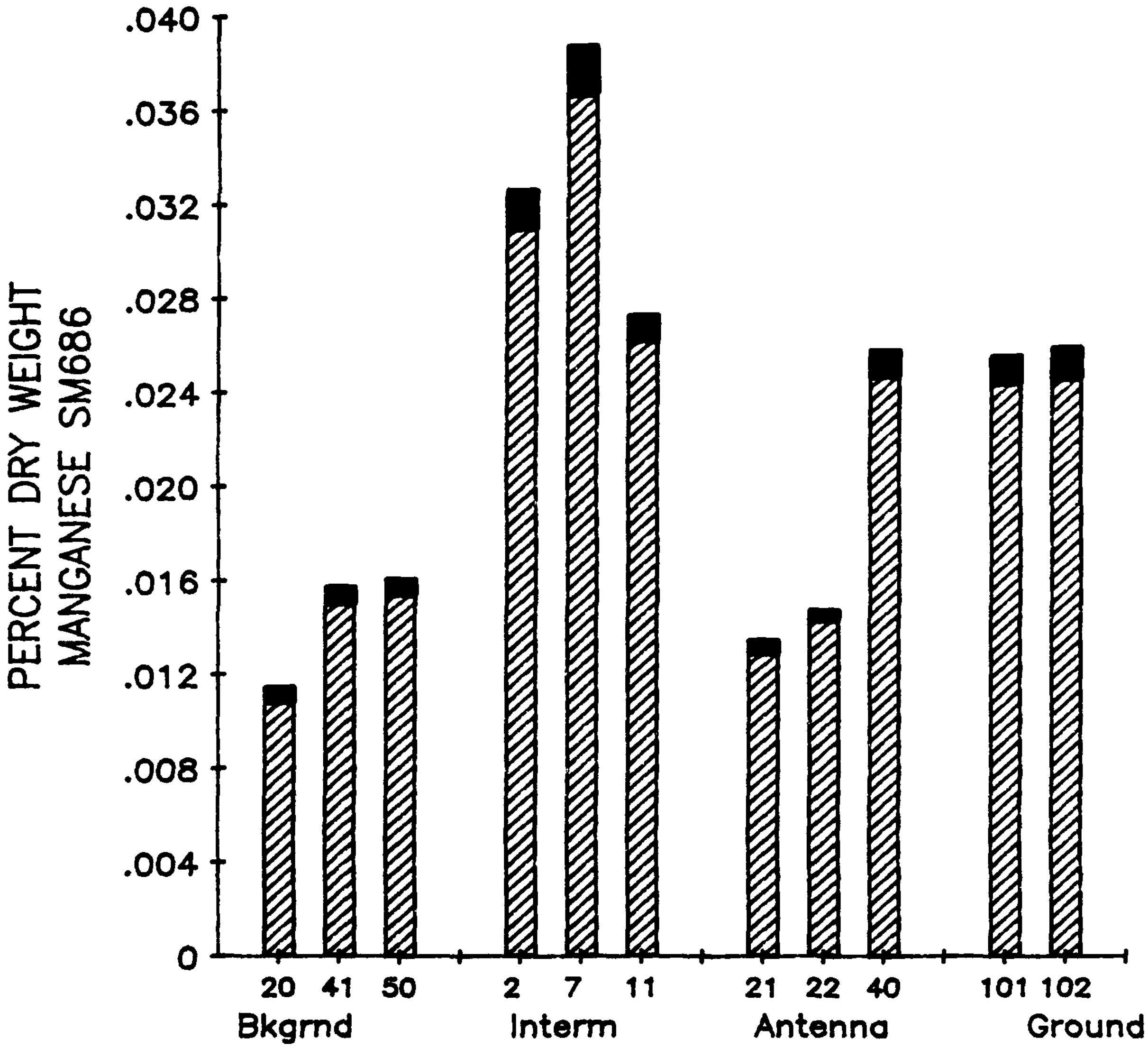


Figure 4.52. Mean manganese concentration of June, 1986 Smilacina trifolia foliar tissue (mean - 1 S.E.).

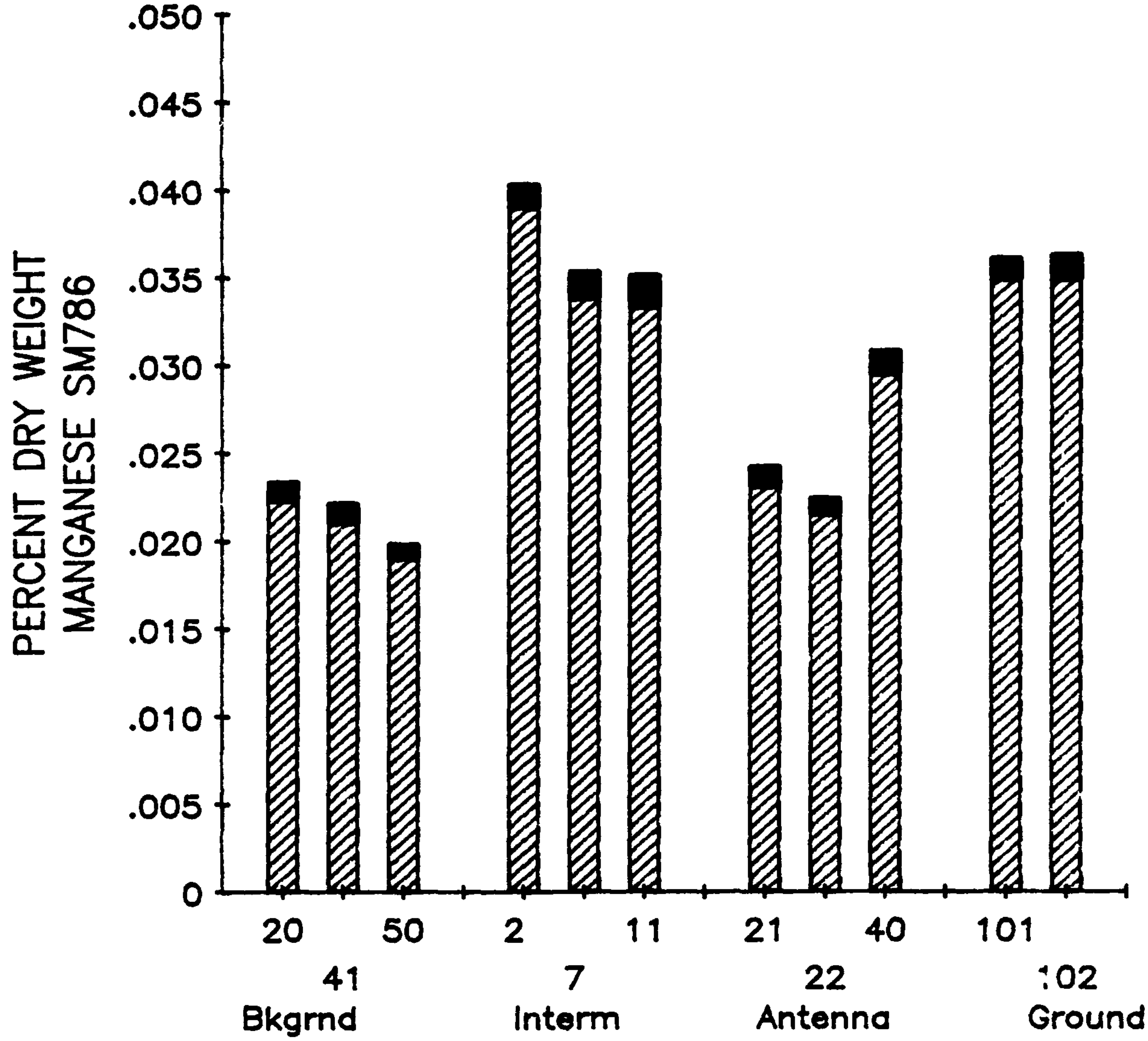


Figure 4.53. Mean (- 1 S.E.) manganese concentration of July, 1986, Smilacina trifolia foliar tissue.

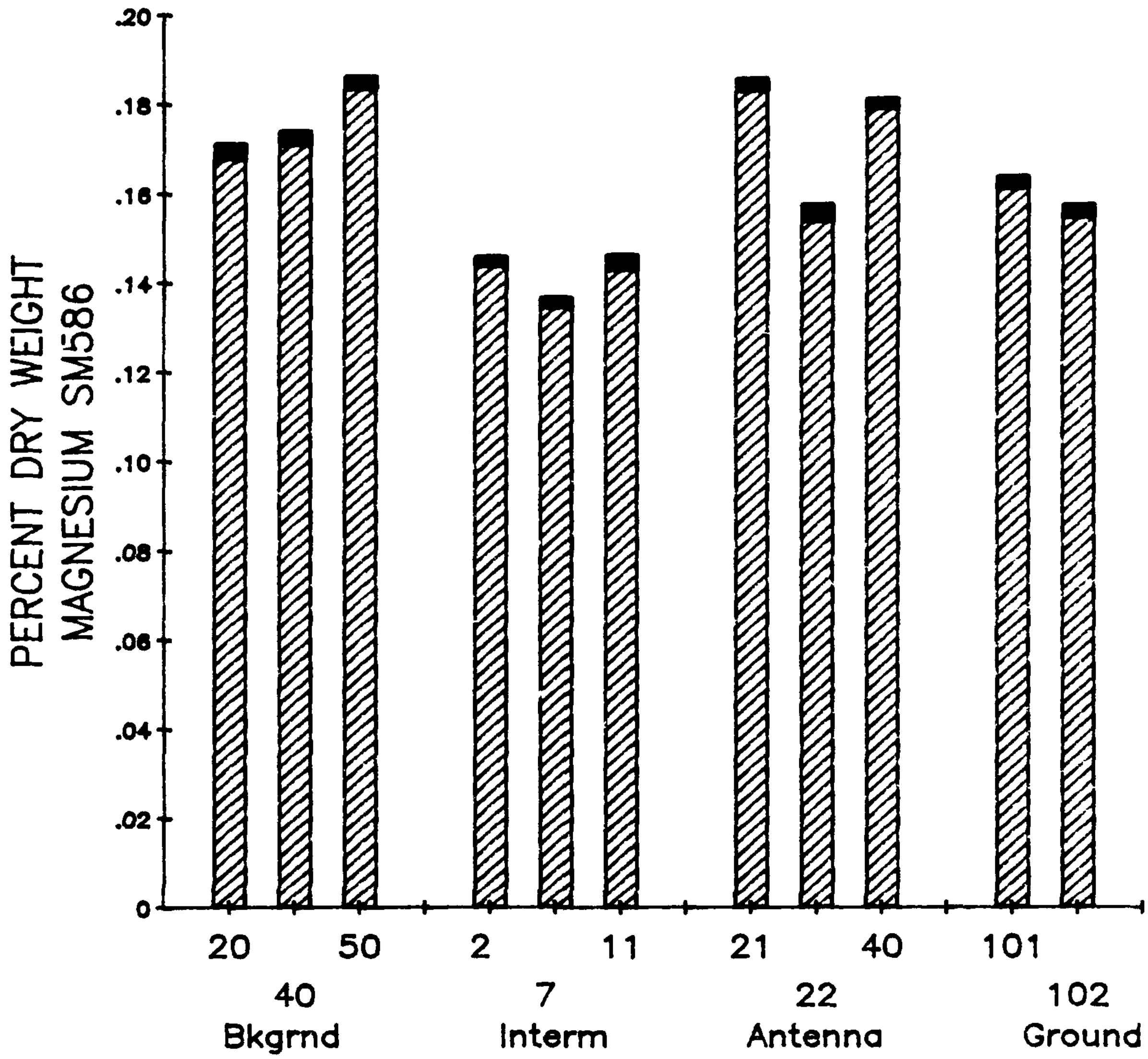


Figure 4.34. Mean (- 1 S.E.) magnesium concentration of May, 1986, Smilacina trifolia foliar tissue.

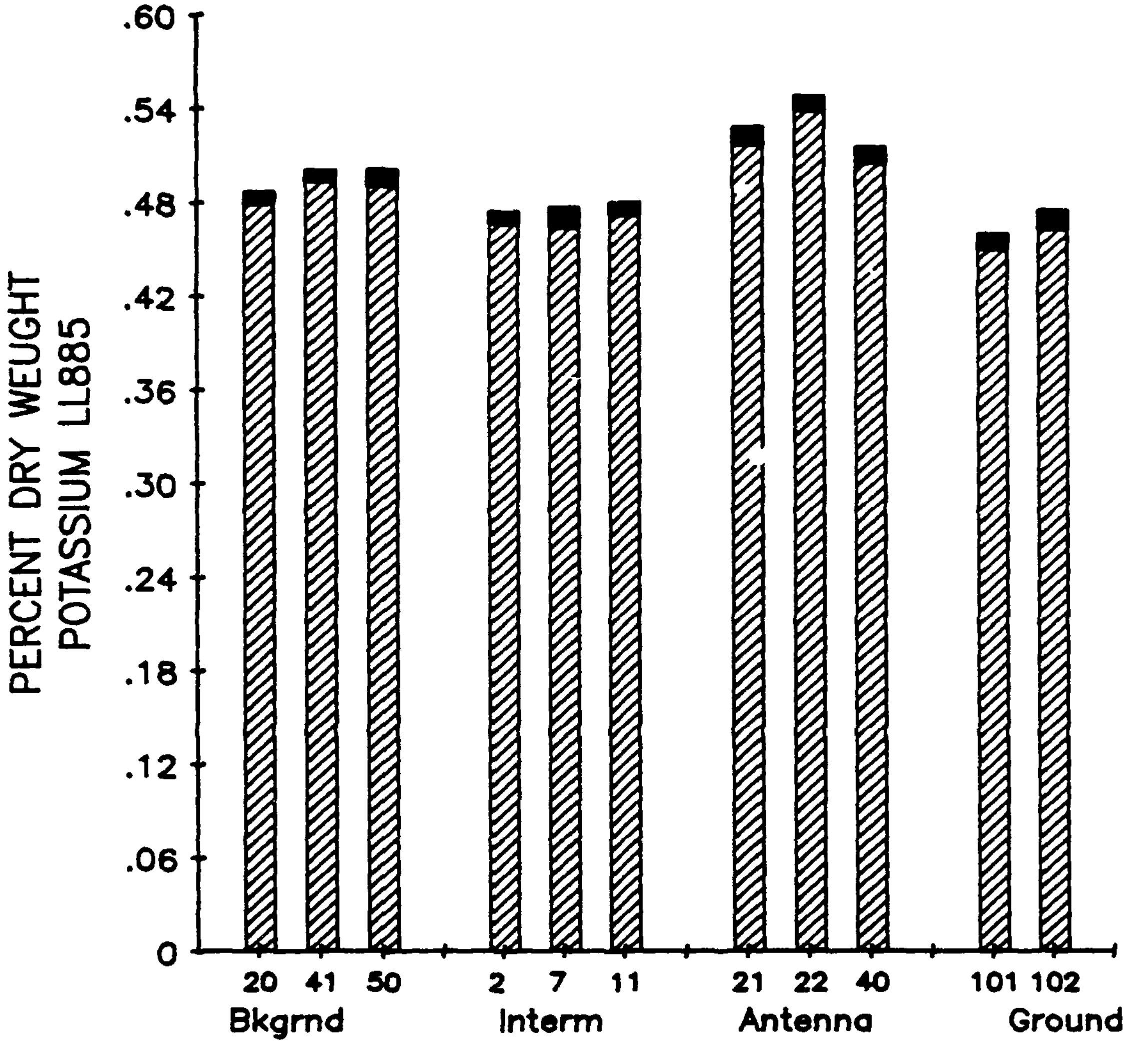


Figure 4.55. Mean (- 1 S.E.) potassium concentration of Chamaedaphne calyculata foliar tissue from Aug., 1985.

Table 4.18. Summary of the multiple regression analyses of foliar nutrient tissue concentrations for the dominant plant species vs environmental and ELF principal components. See the text for an explanation of the independent variables. (*) significant slope at the 0.05 level. a) R^2 is the percentage variation explained b) STb is the standardized regression coefficient.

	Independent Variable	Partial R^2	STB
Smilacina trifolia			
May 1986 (Mg)	MAY863	.05	-.19
	MAY862	.04	.21
	MAY864	.04	-.19
June 1986 (Mn)	MJ864	.07 *	.23
	MJ863	.05	-.27
July 1986 (Mn)	MJJ866	.44 *	.64
	ELF861	.11 *	.31
	MJJ863	.02	.15
Chamaedaphne calyculata			
August 1985 (K)	E85MA3	.16 *	.53
	E85MA4	.11 *	-.35
	ELF851	.09 *	.54
	E85MA1	.05 *	-.30
Ledum groenlandicum			
September 1986 (K)	ELF861	.26 *	.66
	ENV865	.06 *	.27
	ENV866	.06 *	-.24

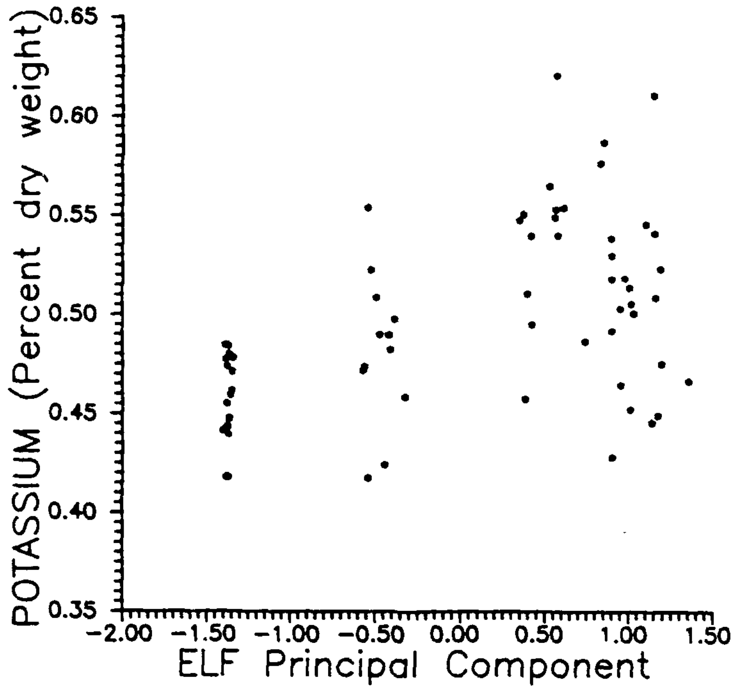


Figure 4.56. The Sept., 1986, plot means of current-year Labrador Tea foliar tissue potassium vs the ELF principal component values associated with each plot.

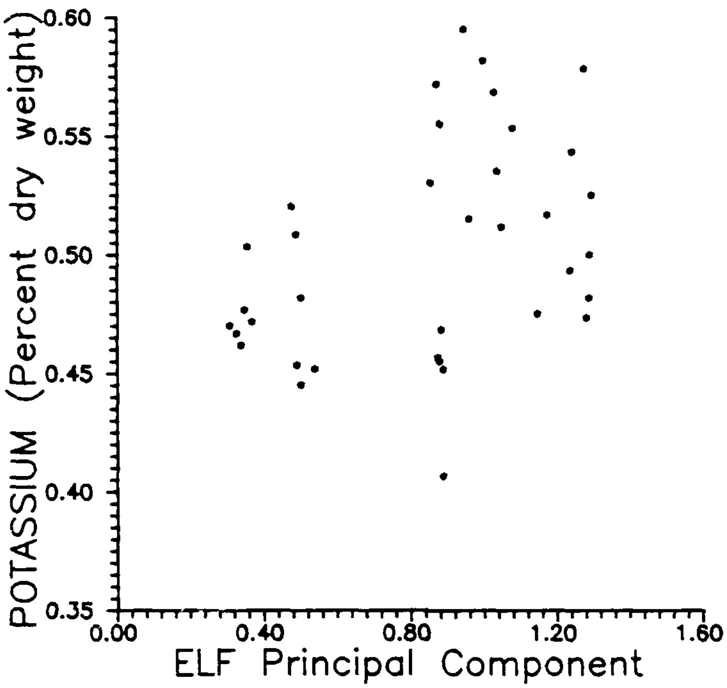


Figure 4.57. The August, 1986, plot means of current-year leatherleaf foliar tissue potassium vs the ELF principal component associated with each plot.

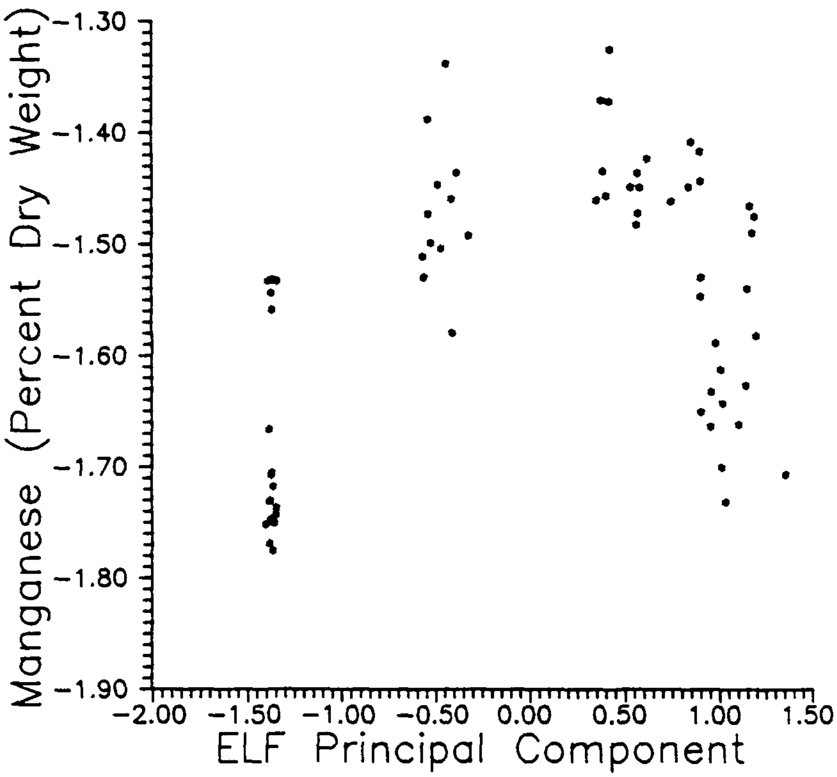


Figure 4.58. The July, 1986, plot means of current-year Smilacina trifolia foliar tissue manganese vs the ELF principal component associated with each plot.
Means were statistically transformed.

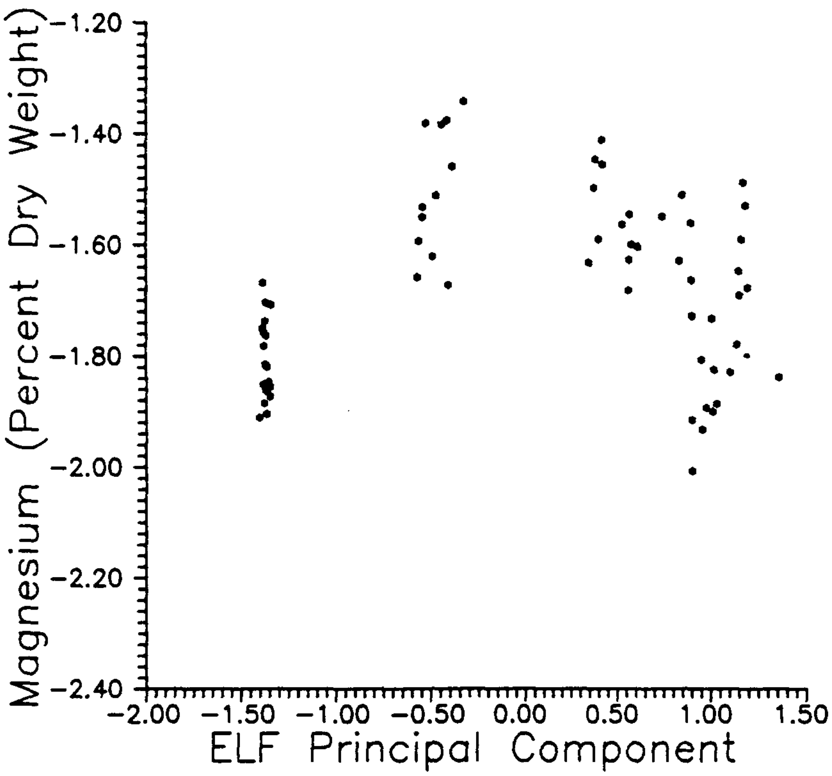


Figure 4.59. The June, 1986, plot means (statistically transformed) for current-year <u>Smilacina trifolia</u> foliar tissue manganese vs the ELF principal component associated with each plot.

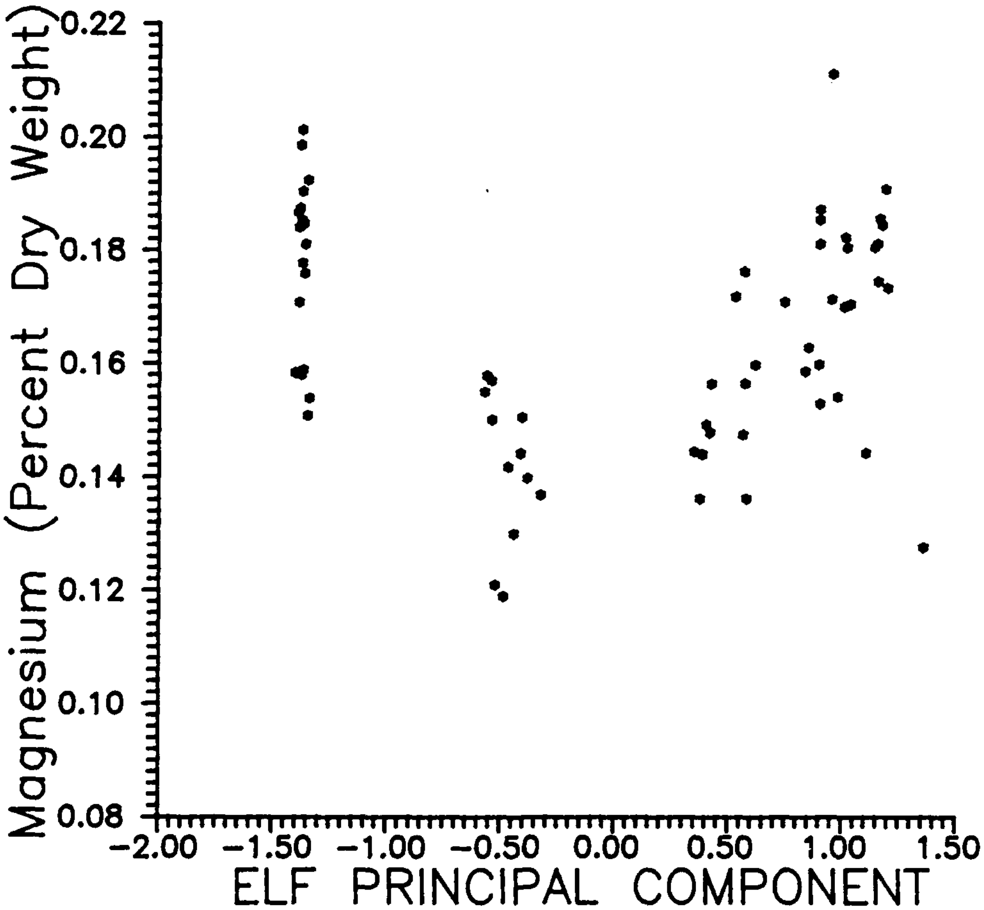


Figure 4.60. The May, 1986, plot means for current-year Smilacina trifolia foliar tissue magnesium vs. the ELF principal component associated with each plot.

included in the model. No clear relationship between nutrient concentration and the ELF component is apparent.

In the previous analyses, each individual nutrient for a species was tested separately; however, plant cells must also maintain balance among nutrients because the behavior of one nutrient element may be influenced by the presence of others. Canonical correlation analysis (CANCORR,SAS) is particularly useful because it takes into account the interrelationship among the dependent variables (which are the different nutrients). In addition, canonical correlation analysis simultaneously analyzes the relationship between the set of variables from the nutrient analysis (dependent variables) and the set of environmental and ELF variables (independent variables) (see STATISTICS section).

Canonical correlation analysis was performed for each data set where a significant NESTED ANOVA occurred in the treatment level. In addition to the canonical correlations we can also examine the weights and loadings associated with each of the canonical variates. The weights, similar to regression coefficients, transform the original variables so the canonical correlation between the dependent and independent data sets is maximal. The loadings are the simple correlation between one of the original variables and its' respective canonical variable. The magnitude of the loadings indicates what proportion of variation in the either the dependent or independent variables is explained by the respective canonical variates. Finally, analysis of the redundancy coefficients (RC) reveals how much of the variation for a canonical variate in one data set is explained by the respective canonical variate in the other data set.

The relatively high canonical correlations (CC) suggest strong associations between the respective canonical variates of the independent and dependent variables (Tables 4.19 - 4.23). However, canonical correlations are by definition maximal; thus their interpretation can be misleading. The relatively low redundancy coefficients demonstrate that only a small proportion of the variation in the data sets is explained by the canonical variates. Because of these limitations, no definitive statement can be made about the relationships between the dependent and independent canonical variates.

SUMMARY

We observed considerable variability in the foliar nutrient content of our test species. Variability existed among sites, between months, and between years. However, because each sample collection period was analyzed independently, we are only concerned with variation among sites within one sampling period.

Only five significant treatment effects were detected in seventy-nine separate anova analyses - a frequency no better than expected by chance alone. These significant differences may well be spurious as evidenced by the fact that they include three different species and three different months. Results of both multiple regression and its' multivariate counterpart, canonical correlation, suggested that ELF fields explained only a small percentage of the variance in foliar nutrient concentration. These results support the null hypothesis that there are no significant differences among treatment means. ELF fields, it appears, have not influenced foliar nutrient concentrations.

Table 4.19. The results of the canonical correlation analysis of the August 1985 <u>Chamaedaphne calyculata</u> foliar nutrient concentrations and the environmental and ELF predictor variables. CC=The canonical correlation coefficient. RC=The redundancy coefficient. The amount of variation in the dependent data set explained by the independent data set.

	Component 1		Component 2		Component 3	
Predictor Set	Load	Weight	Load	Weight	Load	Weight
E85MA1	.15	-.43	.18	.02	.63	.43
E85MA2	-.03	.06	-.88	-.86	.44	.47
E85MA3	.54	.76	-.39	-.32	-.58	-.50
E85MA4	-.47	-.59	-.05	-.07	-.16	-.20
ELF851	.40	.93	.43	.26	.63	.31
EXPLAINED VARIANCE	.14		.23		.33	
Dependent Variables						
Potassium	.93	1.01	-.12	.09	-.35	-.21
Calcium	.20	.35	.09	-.10	.98	.96
Magnesium	-.06	.09	.99	1.03	.13	-.12
EXPLAINED VARIANCE	.30		.33		.37	
CC	.64		.39		.14	
RC	.14		.06		.01	

Table 4.20. The results of the canonical correlation analysis of the May 1986 Smilacina foliar nutrient concentrations and the environmental and ELF predictor variables. CC=The canonical correlation coefficient. RC=The redundancy coefficient.

	Component 1		Component 2		Component 3	
Predictor Set	Load	Weight	Load	Weight	Load	Weight
ELF861	-.45	.14	.51	1.13	.61	.77
May861	-.56	-.65	-.18	-0.93	.34	-.17
May862	.30	.31	.33	.45	-.64	-.56
May863	.56	.60	-.55	- .21	.23	.47
May864	-.52	-.51	-.09	.06	-.40	.30
EXPLAINED VARIANCE	.24		.14		.22	
Dependent Variables						
Phosphorus	.59	.03	.74	1.26	.14	-.51
Potassium	.90	1.06	-.02	-.81	.26	.31
Calcium	.30	.36	.10	.07	.23	.04
Magnesium	.32	-.39	-.20	-.04	.57	.68
Manganese	-.22	-.22	.55	.07	.63	.94
EXPLAINED VARIANCE	.28		.18		.17	
CC	.66		.61		.41	
RC	.12		.07		.03	

Table 4.21. The results of the canonical correlation analysis of the June 1986 Smilacina foliar nutrient concentrations and the environmental and ELF predictor variables. CC=The canonical correlation coefficient. RC=The redundancy coefficient.

	Component 1		Component 2		Component 3	
Predictor Set	Load	Weight	Load	Weight	Load	Weight
ELF861	.03	-.98	.76	.43	.49	.82
MJ861	.43	1.10	.86	.57	.17	-.38
MJ862	-.66	-.80	.31	.37	-.28	-.16
MJ863	.04	-.06	-.29	-.25	.75	.83
MJ864	-.07	-.42	-.08	.07	-.27	.02
EXPLAINED VARIANCE	.12		.30		.20	
Dependent Variables						
Phosphorus	.93	.97	.01	-.14	-.30	-.33
Potassium	-.42	.09	-.77	-.79	-.24	-.44
Calcium	.15	-.05	.01	-.10	-.12	-.59
Magnesium	.31	.12	-.61	-.64	.62	.54
Manganese	.08	.29	.01	.24	.65	.59
EXPLAINED VARIANCE	.23		.19		.19	
CC	.69		.50		.48	
RC	.11		.05		.03	

Table 4.22. The results of the canonical correlation) analysis of the September 1986 Ledum groenlandicum foliar nutrient concentrations and the environmental and ELF predictor variables. CC=The canonical correlation coefficient. RC=The redundancy coefficient. The amount of variation in the dependent data set explained by the independent data set.

	Component 1		Component 2		Component 3	
Predictor Set	Load	Weight	Load	Weight	Load	Weight
ELF861	.35	.05	.73	1.65	.07	-.68
ENV861	.77	.73	.17	-.98	.15	.63
ENV862	-.16	-.16	-.01	-.02	.06	.06
ENV863	.33	.32	-.04	-.09	-.04	-.01
ENV864	.22	.22	.17	.06	.21	.25
ENV865	.43	.46	-.34	.44	-.44	-.76
ENV866	-.13	-.13	-.12	-.22	-.45	-.40
ENV867	-.11	-.11	.19	-.00	-.46	-.38
ENV868	-.11	-.12	.26	.26	.44	.44
EXPLAINED VARIANCE	.12		.09		.10	
Dependent Variables						
Potassium	.60	.45	.68	.60	.28	.78
Calcium	-.59	.36	-.15	-.10	.20	.08
Magnesium	-.53	-.23	.38	.20	.35	.79
Phosphorus	.53	.67	-.77	-.63	.32	.71
Manganese	-.62	-.72	-.48	-.03	.44	.59
EXPLAINED VARIANCE	.33		.29		.11	
CC	.75		.64		.48	
RC	.19		.12		.02	

Table 4.23. The results of the canonical correlation) analysis of the July 1986 Smilacina foliar nutrient concentrations and the environmental and ELF predictor variables. CC=The canonical correlation coefficient. RC=The redundancy coefficient.

	Component 1		Component 2		Component 3	
Predictor Set	Load	Weight	Load	Weight	Load	Weight
ELF861	.36	.17	.18	.94	.61	.02
MJJ1	.33	.22	-.40	-1.06	.80	.79
MJJ2	-.13	-.14	.67	.62	.51	.51
MJJ3	.21	.19	.13	.01	-.21	-.21
MJJ4	-.02	.04	-.21	.16	-.14	-.13
MJJ5	.03	.04	-.10	-.10	-.04	-.04
MJJ6	.90	.90	.16	.11	-.18	-.18
EXPLAINED VARIANCE	.16		.25		.19	
Dependent Variables						
Phosphorus	-.16	-.39	.98	.90	.04	.44
Potassium	-.18	.16	.16	.11	-.58	-.85
Calcium	.35	-.03	-.31	-.02	.47	.96
Magnesium	.36	.03	-.26	-.06	-.20	-.40
Manganese	.93	1.04	.34	.22	.12	-.30
EXPLAINED VARIANCE	.24		.26		.12	
CC	.77		.68		.62	
RC	.14		.11		.05	

NITROGEN FIXATION

Biological nitrogen fixation is important in low nitrogen environments such as peat bogs which receive most of their nutrients from the atmosphere. Several studies have shown that the amount of nitrogen incorporated in peatlands is higher than that potentially supplied by precipitation (Damman 1978, Hemond 1982). This suggests the balance is being recycled or input from other sources. Nitrogen fixation in bogs is carried on by the symbiotic bacteria associated with lichens, mosses, and higher plants; autotrophs such as blue-green algae; and heterotrophic bacteria.

In 1984 we initiated a study using speckled alder (Alnus rugosa) as our model system for studies of potential ELF electromagnetic field effects on nitrogen fixation. Speckled alder is a shrub that forms a symbiotic relationship with a nitrogen fixing bacterium. Use of alder was discontinued because we couldn't propagate enough uniform plants from seed or from cuttings to conduct the studies. We decided to concentrate on nitrogen fixation by heterotrophic microorganisms associated with the peat substrate.

In early spring, 1985, we devloped and field tested a chamber to be used for the acetylene reduction assay. This assay is based on the fact that the nitrogenase enzyme, which reduces atmospheric nitrogen to ammonia, also reduces acetylene to ethylene. Peat and/or plant material was incubated in a chamber with acetylene from which gas samples were then taken. The gas samples were then analyzed with a gas chromatograph for the presence of ethylene. This is a sensitive assay that can detect

low levels of ethylene (Hardy et al. 1968). The amount of ethylene produced can then be converted to the amount of nitrogen produced per unit of moss or peat.

The chambers we used have air tight lids fitted with serum stoppers for the introduction and removal of gases. A standard sized Sphagnum moss (green part only) or a subsurface peat core was placed in the container and then sufficient air removed and acetylene added to to bring the final concentration of acetylene to 10% by volume. The samples were incubated for varying amounts of time. Gas samples were withdrawn at the end of the incubation period and stored in Vacutainers (evacuated blood collection tubes) until they could be analyzed on a gas chromatograph.

Our first experiments with samples collected in a bog near Milwaukee demonstrated that acetylene reduction in peat could be detected. However, subsequent experiments detected no ethylene production in peat samples from bogs in the WTF area. These samples were collected and incubated late in 1985. Chapman and Hemond (1982) report a decrease in ethylene production later in the season and on overcast days. Unfortunately, it rained and was cool during much of the incubation time at the WTF bog sites. Chapmand and Hemmond (1982) also noted a loss of gas from samples stored in Vacutainers for longer than seven days. Our samples had to be transported to our lab facility in Milwaukee and were not analyzed until eight days after after collection. If the amount of ethylene produced was small it could have been lost before the sample could be analyzed.

Two field experiments were conducted in June, 1986. Peat and

peat with attatched moss samples were incubated in open ended jars (similar to our original incubation jars) inserted into the substrate. Moss samples were incubated in closed jars left in the field. Two incubation periods (four hours and twenty-four hours) were used.

Ethylene was detected in all the incubated samples; however, ethylene was also detected in the controls and in certain instances in amounts greater than in the incubated samples. This suggested that either ethylene was present in the acetylene (added to the controls) and/or being produced by the samples themselves. There is some ethylene contamination of the acetylene we used and we had corrected our data to account for this. However, even after correcting for this contamination the ethylene values were still as high or higher in the controls compared to the incubated samples. Some gas leakage was noted, especially during the 24 hour incubations. This introduced additional errors in our results. In the sealed jars containing mosses there was no loss of acetylene; however, ethylene found in these jars was often less than the contamination in the acetylene. These results suggest a background ethylene generation/consumption cycle occurring in the moss/peat system. The acetylene loss we detected in the open-ended jars may have been due to leakage or to a non nitrogen fixing process consuming acetylene.

Two subsequent field experiments in July and August were also inconclusive. Two-hour incubations conducted during July produced no detectable ethylene levels. However, the weather during this time was overcast, cool, and rainy. This may have

affected potential nitrogen fixation. Four-hour incubations conducted during August showed no real differences in ethylene production between incubated samples and controls.

Waughman and Bellamy (1980) did not detect heterotrophic nitrogenase activity in most moist, acidic peat soils they studied. Nitrogen fixation has been suggested to be uncommon in soils with pH less than 5.5 although Waughman and Bellamy did detect some activity in some peat soils with a low pH. However, some heterotrophs such as Clostridium are considered to be acid tolerant so the potential for nitrogen fixation is present. Length of incubation, temperature, water logged soils, and anaerobic conditions may all have an affect on the nitrogen fixation rates.

In our final set of experiments, we collected peat cores during September and Novemeber, 1986 and brought them back to Milwaukee to be incubated under controlled conditions. The cores collected in September, incubated in a glass house for five days, showed low levels of ethylene production and the activity was highly variable (Table 4.24). The November peat cores were incubated in a controlled environmental chamber at constant temperature (25 degrees celsius) and light intensity (400 watts/m^2 for seven days. Values of ethylene production were also low under these conditions but relatively constant (Table 4.24). The coefficients of variability were also similar to those obtained in other work elements of our study.

Our results demonstrated that long-term incubation is required because of the low rate of nitrogen fixation. Also,

incubation under optimally controlled conditions gave much less variability than incubation under semi-controlled conditions. Because of time constraints, the large sample size required because of high variability under field conditions, and problems with our sampling protocol, we decided to drop this work element from further consideration.

Table 4.24 Ethylene generated (micro moles ethylene - cm^{-2} - day^{-1}) in peat cores from bogs of the Wisconsin Test Facility which were incubated under controlled conditions for five to seven days.

September cores

	Bog 7	Bog 50
Mean	.051	.053
Std Error	.020	.017
Coefficient of varaibility	76%	64%
Sample Size	4	4

November cores

	Bog 7
Mean	.029
Std Error	.0023
Coefficient of variability	20%
Sample Size	6

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APPENDIX A. EM FIELD EXPOSURE CRITERIA
(reprinted from IITRI Technical Report E06595-1)

EM EXPOSURE CRITERIA

Because the electromagnetic (EM) intensity and operational characteristics required to produce a bioeffect are not known, EM exposure criteria were established to assist investigators in selecting study sites. The exposure criteria ensure that the 76 Hz EM fields at a test site are significantly larger than the 76 Hz EM fields at the control site, the 60 Hz fields at the test site, and the 60 Hz fields at the control site. In addition, the exposure criteria verify that there is not a substantial difference in the ambient 60 Hz EM field between the test and control sites.

The EM exposure criteria used in site selection are expressed in equation form as follows:

$$T\ (76\ \text{Hz})\ /\ C\ (76\ \text{Hz}) > 10 \qquad (1)$$

$$T\ (76\ \text{Hz})\ /\ T\ (60\ \text{Hz}) > 10 \qquad (2)$$

$$T\ (76\ \text{Hz})\ /\ C\ (60\ \text{Hz}) > 10 \qquad (3)$$

$$0.1 < T\ (60\ \text{Hz})\ /\ C\ (60\ \text{Hz}) < 10 \qquad (4)$$

where: T (76 Hz) = Test site exposure due to ELF system
T (60 Hz) = Test site exposure due to power lines
C (76 Hz) = Control site exposure due to ELF system
C (60 Hz) = Control site exposure due to power lines

Based on the exposure assessment, each possible test and control site pairing was classified as acceptable, conditionally acceptable, or unacceptable. These categories are defined as follows:

> <u>Acceptable</u>. A test/control site pair was placed in this category if it satisfied all four EM exposure inequalities for each of the EM fields applicable to the study. For example, the small mammals and nesting birds studies would be concerned with both the soil and air electric fields as well as the magnetic fields. The soil arthropods and earthworms studies, however, would not be concerned with the electric field in the air, since this field terminates at the earth's surface and would not be expected to impact biota existing in the soil or litter layer.

Conditionally Acceptable. A test/control site pair was placed in this category if it approached, but did not meet, the criteria for acceptability. This category was established since the EM exposure criteria were not rigidly defined. The assumption that a difference of one order of magnitude or more would constitute a significant difference between test and control sites was chosen for these studies, but without knowing what effects will be experienced, if any. It is difficult to define this difference *a priori*. Furthermore, the EM field measurements themselves encompass a certain degree of error, as do any physical measurements.

Unacceptable. A test/control site pair was placed in this category if it neither satisfied the criteria for acceptability nor qualified for conditional acceptability.

APPENDIX B. SUMMARY OF ELF EM FIELD MEASUREMENTS IN BOGS USED IN THE FIELD STUDY
(reprinted from IITRI Technical Report E06595-1)

WETLANDS STUDIES

On 18-21 August 1987, IITRI field crews made ELF electromagnetic (EM) field measurements at 66 measurement points at a total of three antenna, two ground, three control, and three intermediate sites for the wetlands studies. The study sites and measurement points within the study sites were unchanged from 1986.

The positions of the 11 sites relative to the WTF are shown on the composite map in Figure H-1. The site numbers listed on the map are those used by IITRI. Table H-1 provides a cross-reference of IITRI site numbers, investigator site names, and township, range, and section numbers for the sites.

The wetlands studies examine the competitive ability of three types of wetlands plants (herbs, shrubs, and trees) by studying the organismal characteristics of leaf diffusion and cation transport. The functional operation of the decomposer community is also assessed by studying the decomposition rate of standardized cellulose material. The electric and magnetic fields in the earth are considered important EM factors influencing wetlands biota and processes. The electric and magnetic fields in the air can influence any object extending above the surface; for this reason, these fields are also considered important factors influencing wetlands biota and processes. The specific design of the study plots (long and narrow) and their orientation (parallel to the antenna) diminish the need for field gradient measurements across their width (4 m). However, data were taken at measurement points along the length (60 m) of the plots.

Tables H-2, H-3, and H-4 present a summary of the 76 Hz transverse electric field intensities, longitudinal electric field intensities, and magnetic flux densities, respectively, as measured at the study sites. Where available, 76 Hz data from previous years are presented for reference.

Longitudinal electric field and magnetic flux measurements were taken at each site by straddling the water sampling well with the orthogonal legs of the longitudinal electric field probe. The transverse electric field was measured in a clearing as close as possible to the water sampling well.

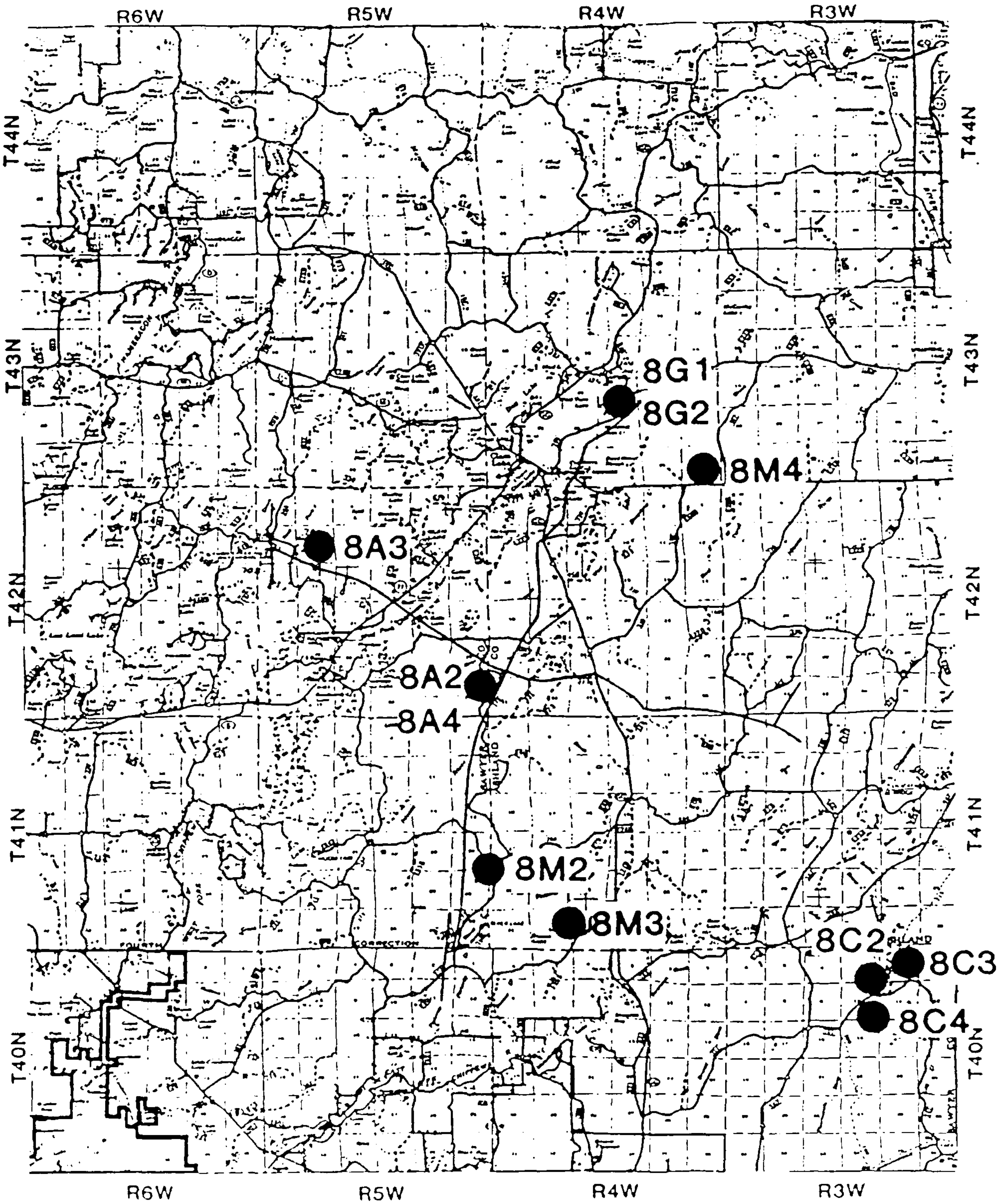

FIGURE H-1. POSITIONS OF WETLAND STUDY SITES RELATIVE TO WISCONSIN TRANSMITTING FACILITY ANTENNA ELEMENTS.

TABLE H-1. SITE NO. CROSS-REFERENCE
Wetlands Studies

IITRI Site No.	Investigator's Site Name	Location Township	:	Range	:	Section(s)
8A2	UW Site 22 Antenna	T42N	:	R4W	:	31
8A3	UW Site 40 Antenna	T42N	:	R5W	:	8
8A4	UW Site 21.2 Antenna	T41N	:	R5W	:	1
8G1	UW Site 10.1 Ground	T43N	:	R4W	:	22
8G2	UW Site 10.2 Ground	T43N	:	R4W	:	22
8C2	UW Site 20 Control	T40N	:	R3W	:	10
8C3	UW Site 41 Control	T40N	:	R3W	:	2
8C4	UW Site 50 Control	T40N	:	R3W	:	10
8M2	UW Site 2 Intermediate	T41N	:	R4W	:	19
8M3	UW Site 7 Intermediate	T41N	:	R4W	:	33
8M4	UW Site 11 Intermediate	T43N	:	R4W	:	36

TABLE H-2. 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Wetlands Studies (page 1 of 3)

Site No., Meas. Pt.	1983		1984		1985	1986	1987
	NS	EW	NS	EW	B(-75)	B(-75)	B(-75)
8A2-A	0.174	0.015	--	--	--	--	--
8A2-B	0.127	0.023	--	--	--	--	--
8A2-C	0.104	0.011	--	--	--	--	--
8A2-1	-	-	0.155	0.051	/	0.141	0.072
8A2-2	-	-	0.142	0.047	/	0.104	0.054
8A2-3	-	-	0.124	0.045	/	0.114	0.053
8A2-4	-	-	0.29	0.088	/	0.177	0.086
8A2-5	-	-	0.55	0.116	/	0.35	0.183
8A2-6	-	-	0.31	0.066	/	0.175	0.116
8A3-A	0.009	0.116	--	--	--	--	--
8A3-B	0.010	0.139	--	--	--	--	--
8A3-C	0.011	0.163	--	--	--	--	--
8A3-1	-	-	0.008	0.144	/	0.130	0.126
8A3-2	-	-	0.008	0.186	/	0.151	0.132
8A3-3	-	-	0.010	0.161	/	0.115	0.121
8A3-4	-	-	0.006	0.160	/	0.137	0.120
8A3-5	-	-	0.007	0.185	/	0.125	0.111
8A3-6	-	-	0.008	0.137	/	0.144	0.122
8A3-7	-	-	0.007	0.153	--	--	--
8A4-1	-	-	0.161	0.007	/	0.066	0.196
8A4-2	-	-	0.155	0.006	/	0.087	0.169
8A4-3	-	-	0.145	0.007	/	0.106	0.121
8A4-4	-	-	0.118	0.005	/	0.095	0.116
8A4-5	-	-	0.089	0.005	/	0.079	0.095
8A4-6	-	-	0.096	0.005	/	0.098	0.083
8C2-A	<0.001	<0.001	--	--	--	--	--
8C2-B	<0.001	<0.001	--	--	--	--	--
8C2-1	-	-	-	-	-	-	-
8C2-2	-	-	-	-	-	-	-
8C2-3	-	-	-	-	-	-	-
8C2-4	-	-	-	-	-	-	-
8C2-5	-	-	-	-	-	-	-
8C2-6	-	-	-	-	-	-	-
8C3-A	<0.001	<0.001	--	--	--	--	--
8C3-B	<0.001	<0.001	--	--	--	--	--
8C3-C	<0.001	<0.001	--	--	--	--	--

TABLE H-2. 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Wetlands Studies (page 2 of 3)

Site No., Meas. Pt.	1983 NS	1983 EW	1984 NS	1984 EW	1985 B(-75)	1986 B(-75)	1987 B(-75)
8C3-1	-	-	-	-	-	-	-
8C3-2	-	-	-	-	-	-	-
8C3-3	-	-	-	-	-	-	-
8C3-4	-	-	-	-	-	-	-
8C3-5	-	-	-	-	-	-	-
8C3-6	-	-	-	-	-	-	-
8C4-A	-	-	<0.001	<0.001	--	--	--
8C4-B	-	-	/	/	--	--	--
8C4-C	-	-	/	/	--	--	--
8C4-1	-	-	-	-	-	-	-
8C4-2	-	-	-	-	-	-	-
8C4-3	-	-	-	-	-	-	-
8C4-4	-	-	-	-	-	-	-
8C4-5	-	-	-	-	-	-	-
8C4-6	-	-	-	-	-	-	-
8G1-A	0.59	0.024	--	--	--	--	--
8G1-B	0.49	0.019	--	--	--	--	--
8G1-C	0.45	0.017	--	--	--	--	--
8G1-1	-	-	0.73	0.010	0.25	0.185	0.147
8G1-2	-	-	0.59	0.006	0.26	0.22	0.184
8G1-3	-	-	0.59	0.006	0.29	0.193	0.172
8G1-4	-	-	0.80	0.008	0.32	0.23	0.154
8G1-5	-	-	0.68	0.006	0.29	0.166	0.126
8G1-6	-	-	0.49	0.004	0.30	0.111	0.124
8G2-A	0.29	0.013	--	--	--	--	--
8G2-B	0.32	0.015	--	--	--	--	--
8G2-C	0.26	0.010	--	--	--	--	--
8G2-1	-	-	/	/	0.25	0.150	0.111
8G2-2	-	-	/	/	0.181	0.117	0.095
8G2-3	-	-	/	/	0.20	0.129	0.113
8G2-4	-	-	0.32	0.003	0.24	0.125	0.109
8G2-5	-	-	0.39	0.005	0.21	0.107	0.093
8G2-6	-	-	0.40	0.004	0.185	0.125	0.111
8M2-A	0.058	0.005	--	--	--	--	--
8M2-B	0.069	0.006	--	--	--	--	--
8M2-C	0.077	0.008	--	--	--	--	--

TABLE H-2. 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Wetlands Studies (page 3 of 3)

Site No.,	1983		1984		1985	1986	1987
Meas. Pt.	NS	EW	NS	EW	B(-75)	B(-75)	B(-75)
8M2-1	-	-	0.054	0.005	0.062	0.047	0.043
8M2-2	-	-	0.059	0.005	/	0.054	0.060
8M2-3	-	-	0.056	0.006	0.066	0.050	0.048
8M2-4	-	-	0.062	0.005	/	0.051	0.052
8M2-5	-	-	0.067	0.006	/	0.057	0.050
8M2-6	-	-	0.074	0.006	0.065	0.058	0.058
8M3-A	0.013	0.005	--	--	--	--	--
8M3-B	0.013	0.007	--	--	--	--	--
8M3-C	0.013	0.005	--	--	--	--	--
8M3-1	-	-	0.016	0.008	0.010	0.006	0.007
8M3-2	-	-	0.018	0.008	/	0.010	0.007
8M3-3	-	-	0.015	0.006	0.009	0.010	0.007
8M3-4	-	-	0.018	0.006	/	0.012	0.009
8M3-5	-	-	0.015	0.005	/	0.010	0.008
8M3-6	-	-	0.013	0.007	0.011	0.009	0.008
8M4-A	/	/	--	--	--	--	--
8M4-B	/	/	--	--	--	--	--
8M4-C	/	/	--	--	--	--	--
8M4-1	-	-	0.010	0.003	/	0.012	0.012
8M4-2	-	-	0.008	0.004	/	0.012	0.012
8M4-3	-	-	0.008	0.004	/	0.008	0.009
8M4-4	-	-	0.007	0.005	/	0.007	0.011
8M4-5	-	-	0.010	0.004	/	0.007	0.011
8M4-6	-	-	0.010	0.003	/	0.008	0.012

NS = north-south antenna.
EW = east-west antenna.
B = both antennas.
\- = site not established.
-- = site dropped.
/ = data not taken.
** = 8G1 and 8G2 data for north-south antenna only.

TABLE H-3. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Wetlands Studies (page 1 of 3)

Site No., Meas. Pt.	1983 NS	1983 EW	1984 NS	1984 EW	1985 B(-75)	1986 B(-75)	1987 B(-75)
8A2-A	138	11.4	--	--	--	--	--
8A2-B	79	13.5	--	--	--	--	--
8A2-C	45	4.1	--	--	--	--	--
8A2-1	-	-	116	36	77	118	64
8A2-2	-	-	98	32	62	100	54
8A2-3	-	-	96	42	60	106	50
8A2-4	-	-	176,177	55,57	111	182	107
8A2-5	-	-	360,370	90,91	264	340	270
8A2-6	-	-	151,153	36	123	147	144
8A3-A	9.8	134	--	--	--	--	--
8A3-B	9.3	142	--	--	--	--	--
8A3-C	9.5	151	--	--	--	--	--
8A3-1	-	-	8.1	137	137	131	136
8A3-2	-	-	7.7	151	144	138	148
8A3-3	-	-	7.4	145	140	138	145
8A3-4	-	-	7.5	126	118	117	119
8A3-5	-	-	7.6	152	137	136	137
8A3-6	-	-	7.8	157	146	146	148
8A3-7	-	-	7.8	131	--	--	--
8A4-1	-	-	149	5.6	171	183	172
8A4-2	-	-	140	5.0	156	155	156
8A4-3	-	-	121	5.4	121	124	115
8A4-4	-	-	117	5.6	104	102	102
8A4-5	-	-	94	4.9	89	91	76
8A4-6	-	-	88	4.9	77	73	74
8C2-A	0.62	0.59	--	--	--	--	--
8C2-B	0.65	0.60	--	--	--	--	--
8C2-1	-	-	/	/	/	0.98	1.02
8C2-2	-	-	/	/	/	1.07	1.09
8C2-3	-	-	/	/	1.07	1.09	1.13
8C2-4	-	-	0.80	0.76	/	1.24	1.23
8C2-5	-	-	0.74	0.70	/	1.04	1.06
8C2-6	-	-	0.62	0.60	/	0.89	0.91
8C3-A	0.81	0.86	--	--	--	--	--
8C3-B	0.77	0.83	--	--	--	--	--
8C3-C	0.85	0.91	--	--	--	--	--

TABLE H-3. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Wetlands Studies (page 2 of 3)

Site No.,	1983		1984		1985	1986	1987
Meas. Pt.	NS	EW	NS	EW	B(-75)	B(-75)	B(-75)
8C3-1	-	-	0.81	0.88	/	1.24	1.30
8C3-2	-	-	0.82	0.97	/	1.26	1.33
8C3-3	-	-	0.84	0.90	1.32	1.30	1.28
8C3-4	-	-	0.85	0.92	/	1.32	1.36
8C3-5	-	-	0.84	0.91	/	1.37	1.35
8C3-6	-	-	0.79	0.85	/	1.22	1.29
8C4-A	-	-	0.93	0.69	--	--	--
8C4-B	-	-	0.72	0.73	--	--	--
8C4-C	-	-	0.72	0.70	--	--	--
8C4-1	-	-	0.83	0.72	/	1.20	1.15
8C4-2	-	-	0.84	0.72	/	1.19	1.17
8C4-3	-	-	0.74	0.73	/	1.13	1.16
8C4-4	-	-	0.85	0.72	1.15	1.15	1.17
8C4-5	-	-	0.82	0.69	/	1.10	1.08
8C4-6	-	-	0.85	0.72	/	1.10	1.13
8G1-A	430	15.9	--	--	--	--	--
8G1-B	490	18.1	--	--	--	--	--
8G1-C	410	14.8	--	--	--	--	--
8G1-1	-	-	420	4.0	195	184	184
8G1-2	-	-	470	4.6	220	200	196
8G1-3	-	-	460	4.5	230	230	230
8G1-4	-	-	470	4.5	230	200	176
8G1-5	-	-	430	4.1	220	185	160
8G1-6	-	-	460	4.4	240	176	156
8G2-A	280	10.9	--	--	--	--	--
8G2-B	310	12.1	--	--	--	--	--
8G2-C	230	9.3	--	--	--	--	--
8G2-1	-	-	280	3.3	184	145	127
8G2-2	-	-	270	3.0	162	134	120
8G2-3	-	-	280	3.3	158	130	130
8G2-4	-	-	260	3.1	143	125	124
8G2-5	-	-	280	3.4	146	121	118
8G2-6	-	-	300	3.7	155	132	142
8M2-A	49	4.8	--	--	--	--	--
8M2-B	55	5.3	--	--	--	--	--
8M2-C	75	6.4	--	--	--	--	--

TABLE H-3. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Wetlands Studies (page 3 of 3)

Site No.,	1983		1984		1985	1986	1987
Meas. Pt.	NS	EW	NS	EW	B(-75)	B(-75)	B(-75)
8M2-1	-	-	52	4.2	51	49	50
8M2-2	-	-	60	4.6	/	56	54
8M2-3	-	-	58	4.7	57	52	54
8M2-4	-	-	57	4.8	/	54	54
8M2-5	-	-	66	5.1	/	59	58
8M2-6	-	-	70	5.3	64	61	65
8M3-A	9.5	4.0	--	--	--	--	--
8M3-B	13.3	6.0	--	--	--	--	--
8M3-C	11.6	3.6	--	--	--	--	--
8M3-1	-	-	11.7	5.1	7.7	7.7	7.4
8M3-2	-	-	12.0	4.9	/	7.4	7.3
8M3-3	-	-	13.5	5.4	9.2	8.7	8.5
8M3-4	-	-	15.1	4.7	/	12.7	14.7
8M3-5	-	-	12.7	4.1	/	10.4	10.6
8M3-6	-	-	13.4	4.5	10	10.1	10.5
8M4-A	6.6	3.1	--	--	--	--	--
8M4-B	2.8	2.8	--	--	--	--	--
8M4-C	3.1	1.02	--	--	--	--	--
8M4-1	-	-	6.9	3.1	5.5	5.2	5.5
8M4-2	-	-	7.2	3.2	/	5.8	5.7
8M4-3	-	-	7.2	3.0	5.5	5.6	5.5
8M4-4	-	-	7.2	2.9	/	5.5	5.5
8M4-5	-	-	7.0	2.9	/	5.7	5.5
8M4-6	-	-	7.0	3.0	5.5	5.6	5.7

NS = north-south antenna.
EW = east-west antenna.
B = both antennas.
- = site not established.
-- = site dropped.
/ = data not taken.
** = 8G1 and 8G2 data for north-south antenna only.

TABLE H-4. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Wetlands Studies (page 1 of 3)

Site No., Meas. Pt.	1983 NS	1983 EW	1984 NS	1984 EW	1985 B(-75)	1986 B(-75)	1987 B(-75)
8A2-A	7.5	0.45	--	--	--	--	--
8A2-B	7.1	0.45	--	--	--	--	--
8A2-C	7.7	0.45	--	--	--	--	--
8A2-1	-	-	7.2	0.23	6.9	7.1	6.4
8A2-2	-	-	7.1	0.23	6.5	6.9	6.2
8A2-3	-	-	7.1	0.23	6.5	6.9	6.1
8A2-4	-	-	7.2	0.23	6.7	6.9	7.0
8A2-5	-	-	7.2	0.23	6.5	6.9	7.0
8A2-6	-	-	7.2	0.23	6.5	6.9	6.9
8A3-A	0.055	22	--	--	--	--	--
8A3-B	0.055	21	--	--	--	--	--
8A3-C	0.054	23	--	--	--	--	--
8A3-1	-	-	0.114	19.1	17.5	18.3	19.2
8A3-2	-	-	0.115	19.5	17.5	18.0	18.7
8A3-3	-	-	0.115	19.4	18.6	18.0	19.0
8A3-4	-	-	0.116	20	17.7	18.3	19.2
8A3-5	-	-	0.116	20	18.5	19.7	19.8
8A3-6	-	-	0.113	18.8	16.5	16.8	17.6
8A3-7	-	-	0.126	23	--	--	--
8A4-1	-	-	8.9	0.154	8.1	8.6	8.6
8A4-2	-	-	8.4	0.167	7.9	8.2	8.3
8A4-3	-	-	8.0	0.158	7.7	8.0	8.3
8A4-4	-	-	8.0	0.158	7.5	7.7	7.9
8A4-5	-	-	7.8	0.159	7.5	7.5	7.3
8A4-6	-	-	8.0	0.161	7.4	7.5	7.9
8C2-A	0.013	0.011	--	--	--	--	--
8C2-B	0.012	0.011	--	--	--	--	--
8C2-1	-	-	/	/	/	0.017	0.017
8C2-2	-	-	/	/	/	0.017	0.017
8C2-3	-	-	/	/	0.016	0.017	0.017
8C2-4	-	-	0.013	0.012	/	0.017	0.017
8C2-5	-	-	0.013	0.012	/	0.017	0.017
8C2-6	-	-	0.013	0.012	/	0.017	0.017
8C3-A	0.013	0.012	--	--	--	--	--
8C3-B	0.013	0.012	--	--	--	--	--
8C3-C	0.013	0.012	--	--	--	--	--

TABLE H-4. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Wetlands Studies (page 2 of 3)

Site No., Meas. Pt.	1983 NS	1983 EW	1984 NS	1984 EW	1985 B(-75)	1986 B(-75)	1987 B(-75)
8C3-1	-	-	0.011	0.011	/	0.015	0.016
8C3-2	-	-	0.011	0.011	/	0.015	0.016
8C3-3	-	-	0.012	0.011	0.015	0.015	0.016
8C3-4	-	-	0.012	0.011	/	0.016	0.015
8C3-5	-	-	0.011	0.010	/	0.016	0.016
8C3-6	-	-	0.012	0.011	/	0.015	0.015
8C4-A	-	-	0.012	0.011	--	--	--
8C4-B	-	-	0.013	0.011	--	--	--
8C4-C	-	-	0.013	0.011	--	--	--
8C4-1	-	-	0.012	0.010	/	0.015	0.015
8C4-2	-	-	0.012	0.010	/	0.015	0.015
8C4-3	-	-	0.012	0.010	/	0.015	0.016
8C4-4	-	-	0.012	0.010	0.015	0.015	0.015
8C4-5	-	-	0.011	0.010	/	0.015	0.015
8C4-6	-	-	0.011	0.010	/	0.015	0.015
8G1-A	2.3	0.083	--	--	--	--	--
8G1-B	2.3	0.083	--	--	--	--	--
8G1-C	2.2	0.081	--	--	--	--	--
8G1-1	-	-	2.1	0.036	1.44	0.74	0.76
8G1-2	-	-	2.2	0.036	1.43	0.76	0.79
8G1-3	-	-	2.2	0.037	1.39	0.74	0.76
8G1-4	-	-	2.1	0.036	1.39	0.74	0.70
8G1-5	-	-	2.1	0.036	1.37	0.74	0.70
8G1-6	-	-	2.0	0.036	1.26	0.66	0.64
8G2-A	0.63	0.038	--	--	--	--	--
8G2-B	0.68	0.054	--	--	--	--	--
8G2-C	0.66	0.039	--	--	--	--	--
8G2-1	-	-	0.64	0.031	0.33	0.22	0.20
8G2-2	-	-	0.64	0.032	0.32	0.22	0.20
8G2-3	-	-	0.67	0.032	0.33	0.23	0.23
8G2-4	-	-	0.68	0.032	0.33	0.23	0.23
8G2-5	-	-	0.69	0.030	0.34	0.22	0.23
8G2-6	-	-	0.72	0.032	0.32	0.22	0.22
8M2-A	0.48	0.074	--	--	--	--	--
8M2-B	0.49	0.077	--	--	--	--	--
8M2-C	0.48	0.076	--	--	--	--	--

TABLE H-4. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Wetlands Studies (page 3 of 3)

Site No., Meas. Pt.	1983 NS	1983 EW	1984 NS	1984 EW	1985 B(-75)	1986 B(-75)	1987 B(-75)
8M2-1	-	-	0.48	0.072	0.50	0.49	0.51
8M2-2	-	-	0.48	0.071	/	0.51	0.52
8M2-3	-	-	0.49	0.071	0.51	0.51	0.51
8M2-4	-	-	0.48	0.072	/	0.51	0.52
8M2-5	-	-	0.49	0.073	/	0.51	0.55
8M2-6	-	-	0.49	0.073	0.51	0.50	0.52
8M3-A	0.080	0.036	--	--	--	--	--
8M3-B	0.080	0.037	--	--	--	--	--
8M3-C	0.078	0.034	--	--	--	--	--
8M3-1	-	-	0.083	0.036	0.098	0.091	0.099
8M3-2	-	-	0.085	0.036	/	0.094	0.097
8M3-3	-	-	0.084	0.036	0.097	0.095	0.097
8M3-4	-	-	0.084	0.038	/	0.093	0.082
8M3-5	-	-	0.084	0.036	/	0.094	0.099
8M3-6	-	-	0.085	0.036	0.096	0.094	0.097
8M4-A	0.101	0.058	--	--	--	--	--
8M4-B	0.100	0.047	--	--	--	--	--
8M4-C	0.088	0.049	--	--	--	--	--
8M4-1	-	-	0.093	0.055	0.082	0.082	0.087
8M4-2	-	-	0.092	0.055	/	0.083	0.085
8M4-3	-	-	0.092	0.054	0.083	0.084	0.085
8M4-4	-	-	0.091	0.054	/	0.081	0.085
8M4-5	-	-	0.091	0.054	/	0.082	0.082
8M4-6	-	-	0.091	0.054	0.082	0.083	0.086

NS = north-south antenna.
EW = east-west antenna.
B = both antennas.
- = site not established.
-- = site dropped.
/ = data not taken.
** = 8G1 and 8G2 data for north-south antenna only.

Comparison of the data in the tables indicates that there were no significant changes in the 76 Hz EM field intensities at the Wisconsin transects in 1987, with the exception of the longitudinal electric fields at site 8A2. The electric fields at this site were again reduced from the 1984 and 1986 values to approximately the 1985 levels, as indicated in Table H-3. This site has a long history of electric field fluctuations for which the only explanation would appear to be seasonal or annual changes in the overall soil conductivity. The slight magnetic field changes noted at site 8A2 are within the range of variation normally associated with the basic repeatability and accuracy of the magnetic field measurements. The ground test sites, 8G1 and 8G2, which experienced EM field changes from 1985 to 1986 due to physical alterations in the WTF north ground, had 1987 EM field levels consistent with those in 1986.

The transverse electric fields in the air were again measured at each site in 1987 when possible. These fields at all sites are highly influenced by nearby vegetation, which can cause significant localized field shielding or enhancement. Therefore, every attempt was made to locate the electric field probe in nearby areas that are generally clear of trees or large shrubs, in order to obtain a relatively unperturbed measurement of the field. These areas were typically within a few meters of the wells. At all wetlands sites, the electric field in the air is generated by the electric field in the earth, and is predominantly horizontal; the overhead antenna wire is too far away to produce a vertical field. The close relationship between the electric fields in the earth and air is easily seen in the data tables for the antenna, ground, and intermediate sites. At the control sites, the intensities of the electric field in the air were estimated to be less than 0.001 V/m, the probe's lower limit of sensitivity. This is based on previous measurement attempts and the measured values of the electric fields in the earth.

As in 1985 and 1986, measurements of 60 Hz ambient EM fields could not be conducted at the WTF, because of its full-time modulated signal operation. 60 Hz EM field data from 1984 and early 1985 were given in the 1985 annual measurement report.*

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*ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1985. IIT Research Institute Technical Report E06549-24, September 1986, 48 pp. plus appendixes.

APPENDIX C. MEAN TREE DENSITY FOR *Picea mariana* and *Larix laricina* IN BOGS SURROUNDING THE WTF

Appendix C. Mean tree density (#/ha) for spruce (Picea mariana) and tamarack (Larix laricina) in bogs surrounding the WTF.

BOG	TOTAL	SPRUCE	TAMARACK
20	3066	2325	729
41	4065	3966	99
50	2637	2370	267
2	2157	2067	99
7	3324	2997	327
11	1728	1668	69
21	3332	2932	400
22	2796	2367	429
40	2526	1896	627
101	2727	1368	1368
102	3195	2127	1068

APPENDIX D. CHANGES IN THE CONDITION OF THE WTF ANTENNA
(reprinted from IITRI Technical Report E06595-1)

4. ANALYSIS OF TRANSMITTER OPERATIONS

4.1 Operating Log Data Base

In order to calculate the field exposure at a study site, investigators must have both field intensity measurements and data on the operating times of the antennas. Field intensity measurements were discussed in Section 3, and data tables are presented in Appendixes A through I. Data on antenna operating conditions are provided to IITRI by the Navy Project Office. These data include all changes in the operating frequency, modulation, power, and phasing for each antenna element. This log information is entered into a computer-based spreadsheet that allows the generation of operating condition summaries in both graphic and tabular form. Graphic summaries for both the WTF and MTF are presented in this section; more detailed tabular summaries appear in Appendix M. IITRI provides the log data bases to investigators on request via computer disk files.

4.2 Summary of WTF Operations, 1984-1987

The WTF has gone through three stages of development from an operational standpoint. The first stage began in the late 1960s, when the WTF was constructed as a test system for a Navy ELF communications system. The test procedures required various modulations, frequencies, currents, and separate as well as simultaneous powering (at various antenna current phase angles) of the antenna elements. This stage was marked by sporadic periods of operation.

The second stage began in early 1985 with the installation of the new transmitter equipment. This stage was marked by short powerings interspersed with long periods when the antenna was not powered.

After this initial test period was completed, the third stage began: the WTF began operational testing, operating nearly 24 hours a day at a predetermined current level, frequency, modulation, and antenna phase angle.

The changes from one stage to the next are represented clearly in the WTF monthly operating summary bar graph of Figure 12. This figure shows the hours of operation on a month-by-month basis for the years 1984-1987. Operation of both antenna elements simultaneously was predominant in 1984, with only sporadic operation of the antenna elements individually. There was little operation of the WTF in the first quarter of 1985, followed by intermittent use in

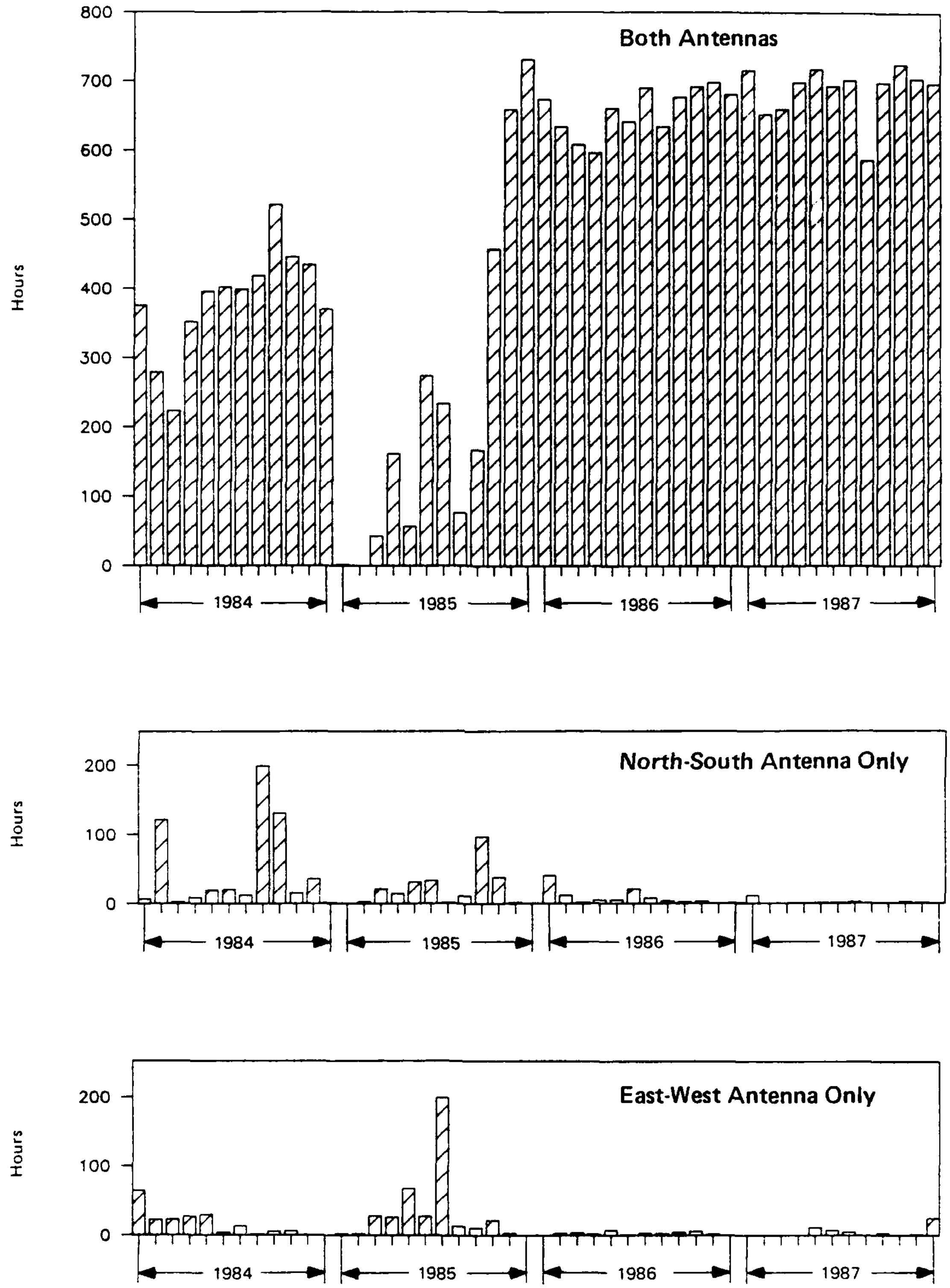


FIGURE 12. WTF MONTHLY OPERATING SUMMARY, 1984-1987.

the second and third quarters, and nearly full-time operation in the fourth quarter. This nearly full-time operation continued through 1986 and 1987.

Figure 13 provides a bar graph of the WTF annual operating summary by mode of operation for 1984-1987. As indicated, the predominant operating condition for all four years was modulated signal transmission at a center frequency of 76 Hz.

The pie charts in Figure 14 provide an annual operating summary by percentage of time per antenna element. As shown, the percentage of time spent in single antenna operation remained relatively constant during 1984 and 1985 and dropped significantly in 1986 and 1987. The total "on" time decreased somewhat in 1985 as a result of the transmitter equipment changeover, and then increased dramatically in 1986 and 1987.

WTF operation from 1984 through 1987 can be summarized as follows:

1984

- The WTF was transmitting about 60% of the time (about 5000 hours) (see Figures 12 and 14).
- About 81% of "on" time was with a modulated 76 Hz signal (see Figure 13).
- About 75% of "on" time was accrued in ~12 hour blocks of continuous operation each day.
- The remaining 25% of "on" time was in short, intermittent time periods, and accounts for most of the transmitter changes in operational mode.
- Less than 2.5% of total "on" time for both antenna elements was at a current level less than 290 amperes.

1985

- The WTF was transmitting about 40% of the time (about 3500 hours) (see Figures 12 and 14).
- About 81% of "on" time was with a modulated 76 Hz signal (see Figure 13).
- About 70% of "on" time was accrued in varying-length blocks of continuous operation each day.
- The remaining 30% of "on" time was in short, intermittent time periods and accounts for most of the transmitter changes in operational mode.
- Less than 1.5% of total "on" time for both antenna elements was at a current level less than 290 amperes.

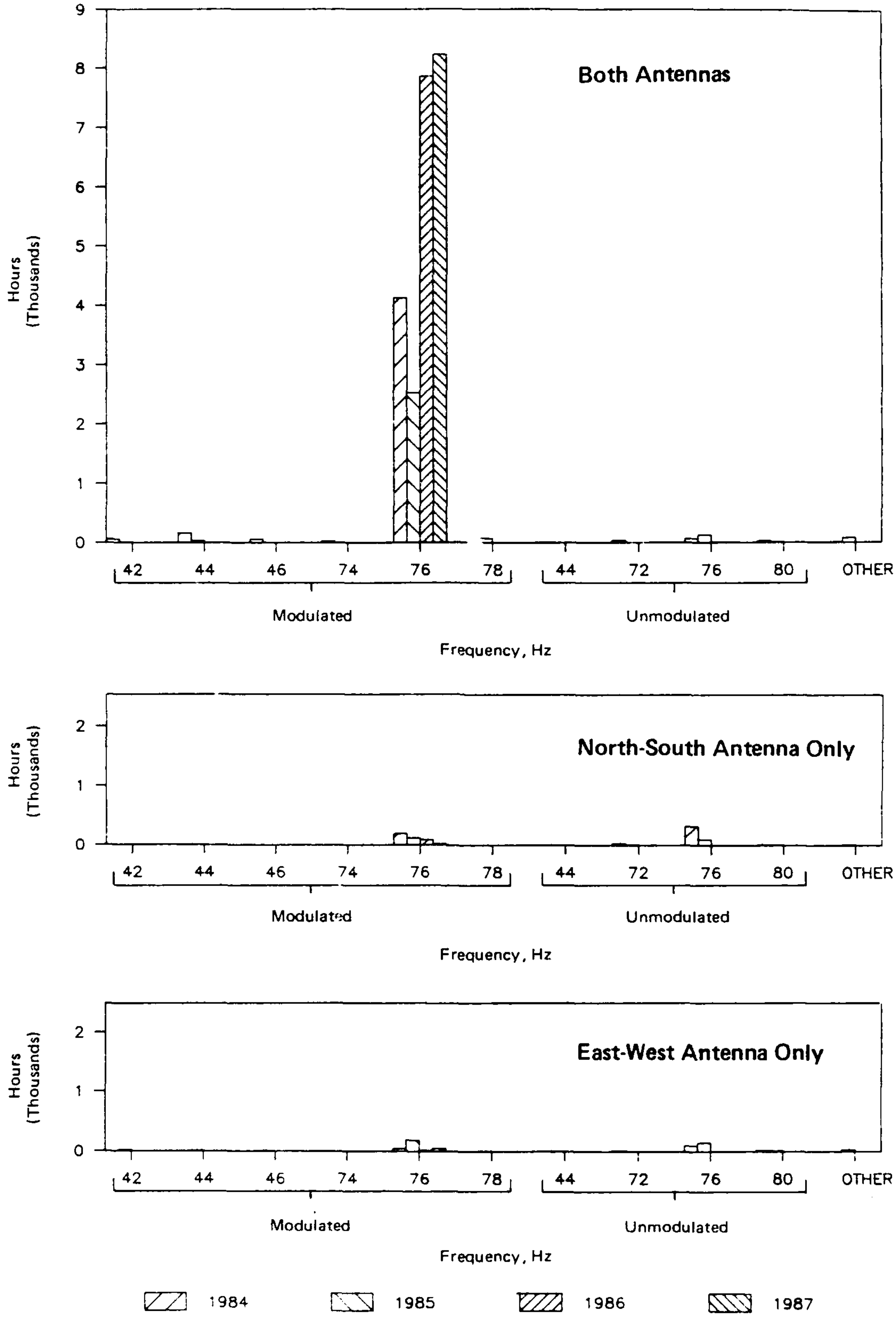


FIGURE 13. WTF OPERATING MODE SUMMARY, 1984-1987.

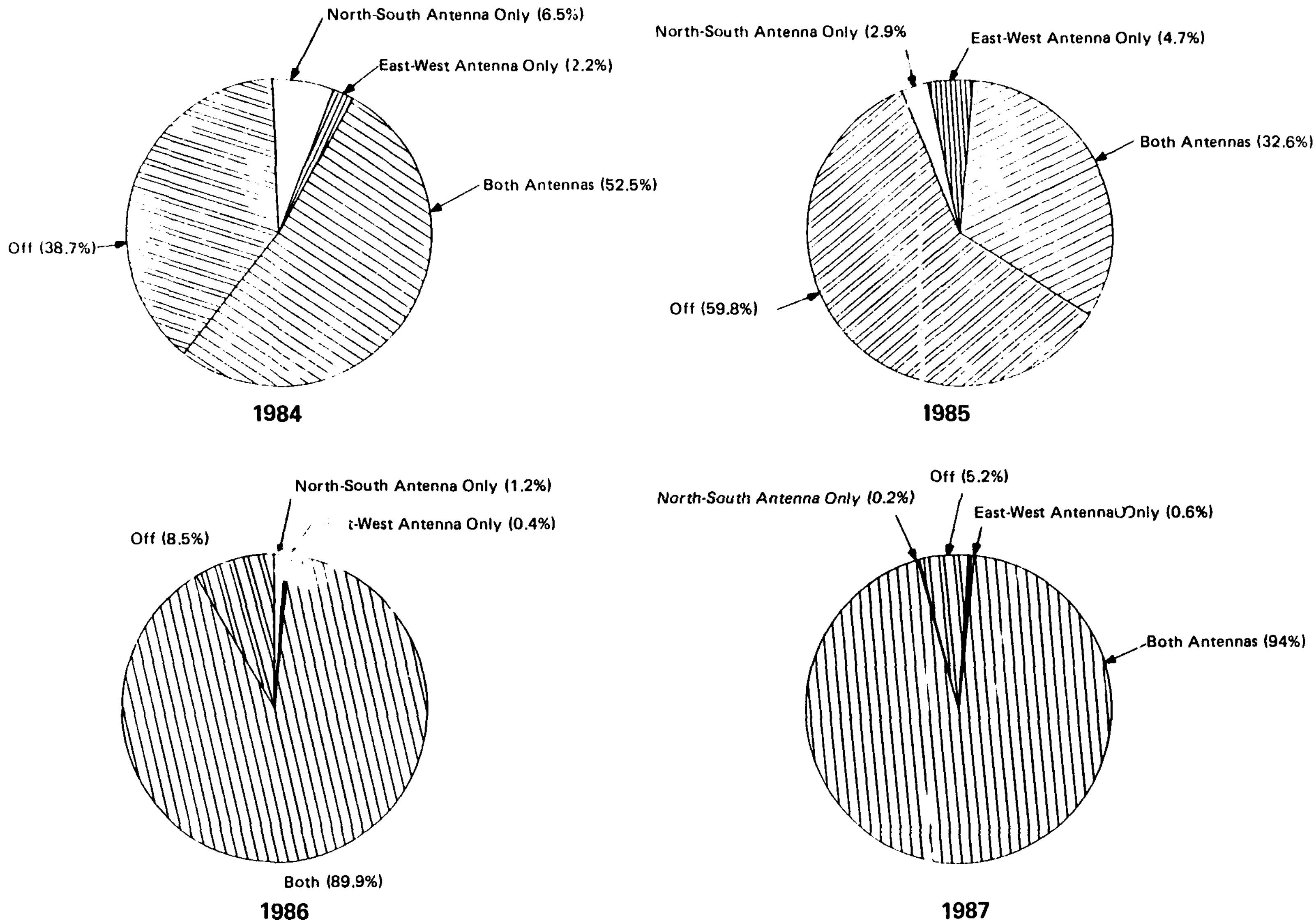


FIGURE 14. WTF OPERATING SUMMARY: PERCENTAGE OF TIME PER ANTENNA ELEMENT, 1984-1987.

1986

- The WTF was transmitting about 91% of the time (about 8000 hours) (see Figures 12 and 14).
- About 99.8% of "on" time was with a modulated 76 Hz signal (see Figure 13).
- The transmitter was off weekly for a four-hour scheduled maintenance period.
- The transmitter was off intermittently because of equipment failure or unscheduled maintenance.
- Less than 1% of total "on" time for both antenna elements was at a current level less than 290 amperes.

1987

- The WTF was transmitting about 95% of the time (about 8300 hours) (see Figures 12 and 14).
- More than 99.9% of "on" time was with a modulated 76 Hz signal (see Figure 13).
- The transmitter was off weekly for a four-hour scheduled maintenance period.
- The transmitter was off intermittently because of equipment failure or unscheduled maintenance (note maintenance period from 24 to 28 August).
- Less than 1% of total "on" time for both antenna elements was at a current level less than 300 amperes.

APPENDIX E. PROTOCOL FOR MEASURING ELF ELECTROMAGNETIC FIELDS IN BOGS USED IN THE FIELD STUDY.

The meter used to measure the output voltages of the probes is a Hewlett-Packard 3581A signal wave analyzer. The HP 3581A functions as a frequency selective rms-calibrated voltmeter with factory modifications for battery and 1 Hz bandwidth operation. A 3 Hz bandwidth is used to measure 60 Hz and unmodulated ELF signals, but a wider bandwidth is needed to measure modulated ELF signals. Because the wider bandwidth will include 60 Hz signals produced by power lines, an IITRI-fabricated active notch filter is placed in series with the wave analyzer when the 60 Hz and ELF signals are of similar magnitudes in order to remove the 60 Hz signals and their harmonics.

3.3 Measurement Techniques

The magnitude of EM fields is determined by the measurement of orthogonal field components. This requires field measurements along three orthogonal axes. For simplicity and repeatability, the axes chosen are the north-south, the east-west, and the vertical. The longitudinal electric field intensity (electric field measured in the earth) has no vertical component; therefore, only the north-south and east-west directional components are measured. In the case of the transverse electric field and the magnetic flux density, all three orthogonal field components are measured. The orthogonal measurements are then used to compute a vector sum or maximum. A drawback to this method is that it yields the correct field maximum only when a single field source is present or dominates. When more than one field source is present, the computed vector sum will be conservative; that is, it will be greater than or equal to the actual maximum.

The following summarizes the technique of orthogonal field measurement:

(1) The magnetic field probe and transverse electric field probe are used to measure three orthogonal components using a compass bearing and the plane of the earth's surface as references. The magnetic field and the transverse electric field are measured in north-south, east-west, and vertical orientations.

(2) The longitudinal electric field is of interest near the surface of the earth, where it will come in contact with biota under study, and has no vertical component. Therefore, only the north-south and east-west orientations are measured.

A geometric presentation of the measurement and summation of orthogonal components is shown in Figure 9. The figure presents the two-dimensional longitudinal electric field geometry and the three-dimensional magnetic field and transverse electric field geometry. The resultant, R, in each case is the vector sum of the individual orthogonal components and is the value reported in data tables.

3.4 Measurement Protocols

3.4.1 Wisconsin Protocol

The WTF was built in the late 1960s to be used as a test facility for ELF communications. It transmitted intermittently from the time of its initial construction until upgrades were made in 1985, after which it transmitted on a full-time basis.

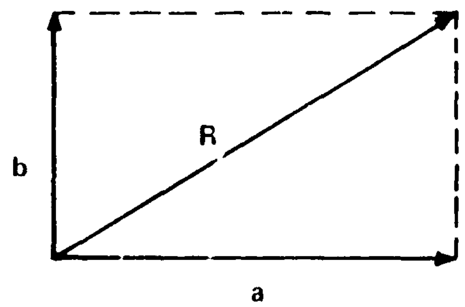
Before 1985, the WTF operated at numerous frequency, modulation, and intensity conditions with either the north-south, the east-west, or both antenna elements being powered. During this period, the antenna was generally under local control, and specific conditions of antenna current, modulation, frequency, and phase angle could be requested for measurements and testing.

In 1985, the WTF was upgraded to a fully operational system with the installation of new transmitters early in the year. The transmitters required testing in mid-year, which allowed only limited manipulation of antenna conditions. This was followed by full-time transmitting during the fourth quarter, which did not allow any control over antenna conditions. The antenna continued full-time transmitting through 1986 and 1987.

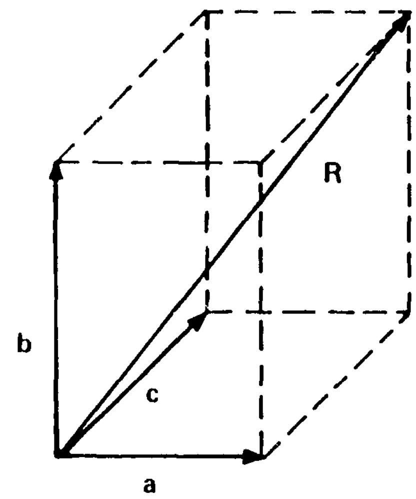
IITRI required control of the WTF antenna for the measurement protocol used prior to 1985; the loss of antenna control therefore required that a new protocol be adopted. The following subsections describe the pre-1985 protocol and the protocol used from 1985 onward.

3.4.1.1 Pre-1985 WTF Protocol

Prior to June 1985, the EM measurement protocol in Wisconsin consisted of making orthogonal sets of measurements of the transverse electric field, longitudinal electric field, and magnetic flux density at each measurement point as follows:



$$R = \sqrt{a^2 + b^2}$$



$$R = \sqrt{a^2 + b^2 + c^2}$$

FIGURE 9. GEOMETRIC PRESENTATION OF THE VECTOR SUM OF ORTHOGONAL MEASUREMENT COMPONENTS.

(1) measurement of the ambient 60 Hz fields with both antenna elements off

(2) measurement of unmodulated 76 Hz fields from the north-south antenna element with the east-west antenna element off

(3) measurement of unmodulated 76 Hz fields from the east-west antenna element with the north-south antenna element off

All measurements were made using a narrow bandwidth meter setting to discriminate the frequency of interest. When necessary, the 76 Hz fields at the WTF measured at lower currents were extrapolated to 300 amperes (full power). Each set of orthogonal components was used to compute a vector sum, or field magnitude. The 76 Hz field magnitudes from the north-south and east-west antenna elements were then added algebraically to compute the worst-case or highest field level that could be produced by both antennas operating simultaneously at any phase angle. These worst-case values were presented in pre-1985 reports.

3.4.1.2 WTF Protocol from 1985 Onward

In 1985, the WTF measurement protocol was modified so that measurements could be made during continuous, phased operation of the two antenna elements. The new protocol, adopted in 1985, was used again in 1986 and 1987 and is outlined below:

(1) The EM fields generated by the ELF Communications System, which are normally modulated with a center frequency of 76 Hz, are measured with a meter bandwidth setting of 30 Hz to accommodate the wider frequency spectrum of the modulated signal.

(2) At control and/or other sites where the 60 Hz ambient fields are comparable to the ELF fields, an IITRI-fabricated active notch filter instrument is used to eliminate the 60 Hz signal from the field measurement.

(3) At each site, the orthogonal components of the magnetic flux density and transverse and longitudinal electric fields are measured, and a vector sum magnitude is computed for each field. The antenna current phase angle is recorded (normally -75° for Wisconsin).

(4) For the six sites where phasing data have been obtained, the longitudinal electric field magnitudes obtained in Step 3 are multiplied by the correction factor from Appendix K to obtain the actual field magnitude.

(5) The 60 Hz ambient fields are unmeasurable unless the ELF transmitter can be turned off (unlikely during fleet transmission), or unless the ambient 60 Hz levels are higher than the ELF-signal-generated "noise" at the same frequency. This latter scenario is likely only at certain control sites. When 60 Hz fields are measured, a narrow bandwidth meter setting is used.

This protocol allows for direct comparisons between pre- and post-1985 data for all but six sites. These six sites--8A2, 8M3, 8M4, 10T6-2, 10T8-4, and 10T10-1--are near enough to both WTF antennas that their EM fields vary with the phasing of the antennas. Appendix K contains tables of conversion factors for these sites that allow comparisons of EM field measurements made in any year at any antenna phasing.

APPENDIX F. SUMMARY STATISTICS FOR THE DECOMPOSITION STUDIES

Appendix F. Summary statistics for the decomposition studies. ELF treatment type: A = antenna, G = ground, I = intermediate, B = background.

Bog	Type	N	Mean Weight Loss (%)	Std. Error	Coef. Var. (%)
Cellulose C3 - Oct., 1983 - June, 1984					
101	G	50	13.44	0.73	38.5
102	G	39	6.99	0.38	34.2
21	A	47	6.66	0.67	69.4
22	A	50	5.55	0.42	53.7
40	A	50	11.41	0.74	45.7
2	I	50	7.28	0.37	36.4
7	I	49	8.21	0.66	56.6
11	I	44	5.85	1.41	160.0
19	B	49	3.87	0.36	65.4
20	B	50	6.57	0.49	52.8
41	B	50	6.42	0.62	68.1
Cellulose C4 - Oct., 1983 - Oct., 1984					
101	G	40	37.29	1.78	30.2
102	G	50	23.15	1.38	40.9
21	A	50	24.23	1.38	40.3
22	A	50	16.90	1.03	43.0
40	A	50	29.88	1.08	25.5
2	I	40	28.04	2.17	48.9
7	I	50	38.04	1.62	30.2
11	I	50	18.41	2.24	86.0
19	B	50	40.13	2.32	40.8
20	B	50	18.25	1.23	47.7
41	B	45	25.36	1.49	39.3
Cellulose C5 - June, 1984 - Oct., 1984					
101	G	48	17.85	0.85	32.9
102	G	48	12.12	1.23	70.2
21	A	44	13.98	1.58	74.9
22	A	48	9.88	1.02	71.5
40	A	44	18.41	1.04	37.4
2	I	52	17.27	1.72	72.0
7	I	48	35.24	3.05	60.0
11	I	48	17.77	1.65	64.2
20	B	48	9.24	0.92	69.1
41	B	36	21.18	1.99	56.3
50	B	32	17.49	2.09	67.6

Appendix F continued.

Bog	Type	N	Mean Weight Loss (%)	Std. Error	Coef. Var. (%)
Cellulose C6 - June, 1984 - June, 1985					
101	G	48	29.52	1.27	29.8
102	G	48	17.55	1.07	42.2
21	A	48	22.89	1.95	58.9
22	A	47	12.53	1.07	58.4
40	A	47	27.56	1.32	32.8
2	I	48	23.71	1.86	54.4
7	I	48	47.59	3.10	45.1
11	I	48	23.99	2.19	63.3
20	B	48	15.73	1.38	60.7
41	B	47	36.09	2.76	52.4
50	B	48	39.19	2.75	48.7
Labrador Tea LT1 - June, 1985 - Oct., 1985					
101	G	48	14.71	0.37	17.5
102	G	48	16.45	0.69	28.9
21	A	47	16.25	0.47	19.9
22	A	48	15.10	0.37	16.8
40	A	47	15.02	0.44	20.0
2	I	48	16.05	0.37	16.1
7	I	47	17.96	0.70	26.8
11	I	48	14.87	0.41	19.1
20	B	48	17.06	0.51	20.5
41	B	48	17.51	0.57	22.6
50	B	48	16.32	0.65	27.4
Labrador Tea LT2 - June, 1985 - June, 1986					
101	G	48	22.74	0.93	28.4
102	G	48	26.15	1.21	32.0
21	A	48	23.26	0.83	24.6
22	A	48	20.52	0.78	26.4
40	A	48	20.31	0.56	18.7
2	I	48	21.94	0.53	16.6
7	I	48	27.54	1.28	32.2
11	I	48	21.09	0.92	30.3
20	B	48	25.38	1.45	39.5
41	B	48	25.45	1.21	32.8
50	B	48	25.42	1.22	33.3

Appendix F continued.

Bog	Type	N	Mean Weight Loss (%)	Std. Error	Coef. Var. (%)
<u>Labrador Tea LT3 - Oct., 1986 - Oct., 1987</u>					
101	G	92	27.32	0.33	11.6
102	G	92	26.91	0.31	11.1
21	A	88	29.55	0.37	11.8
22	A	85	30.44	0.37	11.3
40	A	86	29.31	0.46	14.4
2	I	88	27.57	0.37	12.6
7	I	83	27.66	0.39	12.8
11	I	91	28.18	0.33	11.2
20	B	91	28.5	0.37	12.5
41	B	88	28.56	0.34	11.1
50	B	94	28.54	0.36	12.2

APPENDIX G. RESULTS OF NESTED ANALYSES OF COVARIANCE FOR THE DECOMPOSITION STUDIES

Appendix G. Results of nested analyses of covariance for the decomposition studies. Main effects = Treatment (ELF level = ground, antenna, intermediate, and background), Bog nested within Treatment, Plot nested within Bog (for all except C3 and C4). Initial weight = covariate; * indicates transformation of the weight loss proportion.

Source	df	SS	F	Sign.
<u>Cellulose C3 - Oct., 1983 - June, 1984</u> (*no transf.)				
Treatment	3	0.1208	1.25	NS
Bog within Treatment	7	0.2265	14.87	.0001
Initial Weight	1	0.0032	1.46	NS
Error	516	1.1228		
<u>Cellulose C4 - Oct., 1983 - Oct., 1984</u> (*no transf.)				
Treatment	3	0.2583	0.19	NS
Bog within Treatment	7	3.1033	34.42	.0001
Initial Weight	1	0.0797	6.19	.05
Error	510	6.5681		
<u>Cellulose C5 - June, 1984 - Oct., 1984</u> (*no transf.)				
Treatment	3	0.7810	1.11	NS
Bog within Treatment	7	1.6365	5.25	.0001
Plot within Bog	54	2.4069	5.36	.0001
Initial Weight	1	0.0317	3.81	NS
Error	430	3.5759		
<u>Cellulose C6 - June, 1984 - June, 1985</u> (* square root)				
Treatment	3	0.7931	0.47	NS
Bog within Treatment	7	3.9535	13.43	.0001
Plot within Bog	55	2.3125	3.25	.0001
Initial Weight	1	0.0169	1.31	NS
Error	458	5.9250		
<u>Labrador Tea LT1 - June, 1985 - Oct., 1985</u> (*no transf.)				
Treatment	3	0.0205	1.25	NS
Bog within Treatment	7	0.0384	3.00	.01
Plot within Bog	55	0.1007	1.51	.05
Initial Weight	1	0.0010	0.85	NS
Error	458	0.5551		

Appendix G continued.

Source	df	SS	F	Sign.
Labrador Tea LT2 - June, 1985 - June, 1984 (* inverse)				
Treatment	3	25.5424	1.34	NS
Bog within Treatment	7	44.5055	4.32	.001
Plot within Bog	55	81.0097	1.22	NS
Initial Weight	1	0.1816	0.15	NS
Error	461	554.5271		
Labrador Tea LT3 - Oct., 1986 - Oct., 1987 (*inverse)				
Treatment	3	12.7654	18.60	.001
Bog within Treatment	7	1.6013	0.71	NS
Plot within Bog	55	17.6825	2.01	NS
Initial Weight	1	0.1788	1.12	NS
Error	911	145.7097		

APPENDIX H. SUMMARY OF <u>Ledum groenlandicum</u> STOMATAL RESISTANCE MEASUREMENTS FOR 1986 AND 1987

Appendix H. Summary of *Ledum groenlandicum* stomatal resistance measurements (s/cm) for 1986 and 1987.

BOG	MEAN	SE	N	CV
JULY, 1986				
20	2.02	.05	30	11
41	2.18	.07	30	16
50	2.06	.07	30	18
2	1.86	.05	30	16
7	2.12	.05	30	12
11	2.07	.07	30	19
21	1.29	.04	30	11
22	1.83	.03	30	09
40	1.49	.03	30	18
101	1.85	.04	30	10
102	2.06	.05	30	14
AUGUST, 1986				
20	2.10	.05	30	14
41	1.98	.04	30	12
50	1.84	.06	30	17
2	2.07	.06	30	17
7	2.28	.07	30	17
11	2.02	.05	30	14
21	1.78	.08	30	24
22	2.40	.06	30	14
40	1.85	.07	30	20
101	1.97	.06	30	16
102	1.91	.06	30	18
JULY, 1987				
20	1.68	.03	60	13
41	1.69	.02	60	10
50	1.72	.03	60	14
2	1.88	.07	60	27
7	1.78	.05	60	24
11	2.09	.07	60	26
21	1.69	.02	60	10
22	1.57	.03	60	15
40	1.65	.03	60	15
101	1.60	.03	60	14
102	1.50	.02	60	10

Appendix H (continued)

AUGUST, 1987

20	2.07	.04	60	14
41	1.99	.08	60	32
50	2.12	.04	60	15
2	1.65	.02	60	9
7	2.91	.07	60	19
11	2.62	.05	60	15
21	3.12	.07	60	17
22	2.70	.07	60	19
40	3.11	.07	60	16
101	2.30	.06	60	19
102	2.32	.05	60	16

APPENDIX I. SUMMARY STATISTICS FOR FOLIAR CATION CONCENTRATIONS (PERCENT DRY WEIGHT) OF SELECTED BOG SPECIES

Appendix I. Summary statistics for cation concentrations (percent dry weight) in <u>Chamaedaphne calyculata</u>.

JUNE, 1985

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	K	36	.77	.031	23.86
	Ca	36	.41	.014	20.66
	Mg	36	.13	.004	17.18
41	K	36	.69	.028	24.21
	Ca	36	.40	.014	20.36
	Mg	36	.13	.003	12.36
50	K	36	.79	.032	24.06
	Ca	36	.42	.016	23.06
	Mg	36	.13	.003	12.03
2	K	36	.57	.011	11.31
	Ca	36	.44	.014	19.21
	Mg	36	.13	.003	12.03
7	K	36	.66	.013	11.87
	Ca	36	.36	.010	16.36
	Mg	36	.13	.002	11.71
11	K	36	.67	.014	12.42
	Ca	36	.39	.018	27.82
	Mg	36	.11	.002	11.18
21	K	36	.66	.013	11.95
	Ca	36	.42	.011	16.02
	Mg	36	.12	.002	10.24
22	K	36	.69	.018	15.21
	Ca	36	.39	.010	14.73
	Mg	36	.10	.002	13.06
40	K	36	.56	.013	14.26
	Ca	36	.37	.011	17.99
	Mg	36	.11	.002	12.46
101	K	36	.56	.013	13.91
	Ca	36	.46	.016	20.83
	Mg	36	.13	.003	15.57
102	K	36	.60	.013	13.11
	Ca	36	.35	.012	21.55
	Mg	36	.12	.003	14.93

Appendix I. Summary statistics for cation concentrations (percent dry weight) in _Chamaedaphne calyculata_.

August, 1985

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	K	36	.49	.008	10.10
	Ca	36	.55	.014	15.23
	Mg	36	.12	.003	13.76
41	K	36	.50	.007	8.79
	Ca	36	.62	.026	24.71
	Mg	36	.12	.003	13.13
50	K	36	.50	.011	13.39
	Ca	36	.50	.014	17.20
	Mg	36	.12	.003	15.90
2	K	36	.48	.008	10.07
	Ca	36	.59	.013	13.67
	Mg	36	.12	.003	13.37
7	K	36	.48	.013	16.69
	Ca	36	.52	.019	22.44
	Mg	36	.12	.004	18.13
11	K	36	.48	.008	10.45
	Ca	36	.65	.020	18.11
	Mg	36	.10	.003	17.32
21	K	36	.53	.011	12.94
	Ca	36	.65	.023	20.91
	Mg	36	.13	.003	14.26
22	K	36	.55	.009	10.38
	Ca	36	.58	.016	16.93
	Mg	36	.11	.003	17.05
40	K	36	.52	.010	12.15
	Ca	36	.56	.017	18.37
	Mg	36	.12	.003	13.70
101	K	36	.46	.010	13.28
	Ca	36	.65	.023	20.98
	Mg	36	.14	.003	13.71
102	K	36	.48	.013	15.74
	Ca	36	.54	.022	24.41
	Mg	36	.13	.003	11.78

Appendix I. Summary statistics for cation concentrations (percent dry weight) in <u>Chamaedaphne calyculata</u>.

SEPTEMBER, 1985

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	K	36	.52	.007	8.54
	Ca	36	.57	.018	18.79
	Mg	36	.11	.003	17.43
41	K	36	.54	.012	13.60
	Ca	36	.63	.031	29.56
	Mg	36	.12	.003	15.78
50	K	36	.52	.008	8.77
	Ca	36	.58	.018	18.40
	Mg	36	.11	.003	18.55
2	K	36	.49	.008	9.87
	Ca	36	.70	.023	19.90
	Mg	36	.13	.004	17.98
7	K	36	.50	.011	13.30
	Ca	36	.61	.022	21.35
	Mg	36	.11	.004	19.15
11	K	36	.48	.004	5.49
	Ca	36	.73	.019	15.72
	Mg	36	.10	.002	13.28
21	K	36	.51	.010	11.40
	Ca	36	.65	.020	18.33
	Mg	36	.13	.003	13.92
22	K	36	.56	.011	11.58
	Ca	36	.62	.018	17.16
	Mg	36	.10	.003	16.34
40	K	36	.50	.008	9.79
	Ca	36	.69	.021	18.45
	Mg	36	.13	.004	17.37
101	K	36	.50	.009	11.01
	Ca	36	.70	.026	22.14
	Mg	36	.13	.003	14.06
102	K	36	.50	.008	10.15
	Ca	36	.58	.019	19.62
	Mg	36	.12	.004	19.16

Appendix I. Summary statistics for cation concentrations (percent dry weight) in <u>Chamaedaphne calyculata</u>.

June, 1986

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	P	36	.22	.006	15.47
	K	36	.75	.016	13.09
	Ca	36	.38	.013	19.57
	Mg	36	.12	.003	15.36
	Mn	36	.06	.004	42.68
41	P	36	.22	.005	12.93
	K	36	.75	.017	13.78
	Ca	36	.38	.015	23.63
	Mg	36	.12	.003	14.97
	Mn	36	.05	.004	41.65
50	P	18	.21	.006	12.17
	K	18	.76	.015	8.37
	Ca	18	.37	.008	8.96
	Mg	18	.13	.003	9.71
	Mn	18	.05	.003	26.94
2	P	36	.22	.006	16.91
	K	36	.66	.012	11.16
	Ca	36	.46	.010	12.91
	Mg	36	.14	.002	7.78
	Mn	36	.06	.004	34.78
7	P	36	.22	.006	17.75
	K	36	.68	.014	12.49
	Ca	36	.40	.012	18.69
	Mg	36	.13	.003	13.34
	Mn	36	.04	.003	36.73
11	P	35	.21	.006	18.52
	K	35	.74	.018	13.96
	Ca	35	.40	.012	17.74
	Mg	35	.11	.003	14.91
	Mn	35	.08	.004	32.93
21	P	35	.22	.004	10.31
	K	35	.78	.011	8.27
	Ca	35	.43	.012	16.61
	Mg	35	.13	.002	9.47
	Mn	35	.06	.003	29.57
22	P	36	.18	.004	12.82
	K	36	.72	.014	11.64
	Ca	36	.42	.013	19.07
	Mg	36	.12	.002	10.90
	Mn	36	.05	.003	34.64

June, 1986 (continued)

BOG	VARIABLE	N	MEAN	STD ERR	CV
40	P	36	.18	.008	27.51
	K	36	.61	.011	10.67
	Ca	36	.39	.011	17.34
	Mg	36	.12	.002	12.00
	Mn	36	.07	.004	35.40
101	P	36	.22	.007	18.75
	K	36	.73	.014	11.57
	Ca	36	.43	.014	19.72
	Mg	36	.14	.003	14.38
	Mn	36	.06	.004	34.81
102	P	36	.21	.006	15.75
	K	36	.72	.010	8.43
	Ca	36	.38	.011	17.15
	Mg	36	.14	.002	8.95
	Mn	36	.05	.003	34.25

Appendix I. Summary statistics for cation concentrations (percent dry weight) in <u>Chamaedaphne calyculata</u>.

July, 1986

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	P	36	0.16	0.003	13.24
	K	36	0.57	0.011	11.56
	Ca	36	0.44	0.013	18.18
	Mg	36	0.12	0.003	16.33
	Mn	36	0.09	0.003	23.40
41	P	36	0.16	0.003	11.42
	K	36	0.58	0.014	14.06
	Ca	36	0.56	0.020	21.61
	Mg	36	0.15	0.003	12.78
	Mn	36	0.09	0.004	23.65
50	P	36	0.19	0.003	10.74
	K	36	0.67	0.014	12.73
	Ca	36	0.37	0.010	15.84
	Mg	36	0.12	0.002	10.75
	Mn	36	0.07	0.002	21.14
2	P	36	0.21	0.004	10.99
	K	36	0.65	0.017	15.70
	Ca	36	0.46	0.012	16.22
	Mg	36	0.14	0.002	10.37
	Mn	36	0.08	0.004	30.21
7	P	36	0.21	0.006	18.24
	K	36	0.65	0.016	14.85
	Ca	36	0.45	0.015	19.88
	Mg	36	0.13	0.003	12.19
	Mn	36	0.06	0.005	46.45
11	P	36	0.15	0.004	16.63
	K	36	0.53	0.010	11.47
	Ca	36	0.48	0.012	15.44
	Mg	36	0.11	0.003	14.04
	Mn	36	0.11	0.004	25.08
21	P	36	0.17	0.003	11.71
	K	36	0.62	0.013	12.50
	Ca	36	0.53	0.017	19.20
	Mg	36	0.14	0.003	11.12
	Mn	36	0.09	0.004	29.19
22	P	36	0.15	0.004	15.47
	K	36	0.65	0.014	12.53
	Ca	36	0.47	0.017	22.30
	Mg	36	0.12	0.003	12.40
	Mn	36	0.07	0.004	34.04

JULY, 1986 (continued)

40	P	36	0.13	0.004	16.10
	K	36	0.53	0.012	13.09
	Ca	36	0.54	0.016	17.44
	Mg	36	0.13	0.004	17.36
	Mn	36	0.10	0.005	32.06
101	P	36	0.16	0.003	10.81
	K	36	0.63	0.01	12.64
	Ca	36	0.46	0.015	20.05
	Mg	36	0.13	0.003	11.48
	Mn	36	0.07	0.003	22.71
102	P	36	0.17	0.003	11.22
	K	36	0.67	0.016	14.65
	Ca	36	0.39	0.010	15.88
	Mg	36	0.13	0.002	10.64
	Mn	36	0.06	0.002	23.48

Appendix I. Summary statistics for cation concentrations (percent dry weight) in Chamaedaphne calyculata.

September, 1986

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	P	36	0.12	0.002	12.23
	K	36	0.46	0.007	8.74
	Ca	36	0.63	0.017	16.48
	Mg	36	0.13	0.003	15.01
	Mn	36	0.15	0.007	28.89
41	P	36	0.133	0.002	10.36
	K	36	0.47	0.013	16.30
	Ca	36	0.71	0.025	21.11
	Mg	36	0.14	0.003	14.91
	Mn	36	0.13	0.008	36.77
50	P	36	0.13	0.004	19.79
	K	36	0.44	0.005	7.23
	Ca	36	0.61	0.013	13.51
	Mg	36	0.12	0.003	13.41
	Mn	36	0.13	0.006	30.04
2	P	36	0.14	0.003	13.86
	K	36	0.46	0.009	11.32
	Ca	36	0.76	0.025	19.42
	Mg	36	0.15	0.003	13.66
	Mn	36	0.14	0.008	32.00
7	P	36	0.15	0.003	12.67
	K	36	0.46	0.008	10.79
	Ca	36	0.71	0.026	21.81
	Mg	36	0.14	0.005	19.15
	Mn	36	0.11	0.005	26.50
11	P	36	0.11	0.001	7.18
	K	36	0.44	0.005	6.63
	Ca	36	0.72	0.020	16.82
	Mg	36	0.13	0.003	13.34
	Mn	36	0.15	0.006	23.71
21	P	36	0.14	0.003	11.06
	K	36	0.51	0.014	16.22
	Ca	36	0.76	0.020	15.73
	Mg	36	0.15	0.004	16.93
	Mn	36	0.14	0.006	23.93
22	P	36	0.12	0.003	14.98
	K	36	0.53	0.015	16.56
	Ca	36	0.67	0.022	19.49
	Mg	36	0.13	0.003	13.35
	Mn	36	0.12	0.006	30.60

September, 1986 (continued)

40	P	36	0.13	0.002	10.21
	K	36	0.44	0.009	12.82
	Ca	36	0.68	0.020	17.44
	Mg	36	0.14	0.003	14.98
	Mn	36	0.13	0.005	24.44
101	P	36	0.11	0.002	10.73
	K	36	0.48	0.011	14.00
	Ca	36	0.70	0.024	20.15
	Mg	36	0.13	0.004	17.44
	Mn	36	0.11	0.005	28.71
102	P	36	0.13	0.003	14.24
	K	36	0.49	0.008	9.83
	Ca	36	0.57	0.019	19.82
	Mg	36	0.14	0.004	18.99
	Mn	36	0.11	0.004	20.13

Appendix I. Summary statistics for cation concentrations (percent dry weight) in <u>Smilacina trifolia</u>.

JUNE, 1985

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	K	36	2.74	0.065	14.22
	Ca	36	0.34	0.010	18.55
	Mg	36	0.16	0.004	14.65
41	K	36	3.22	0.089	16.55
	Ca	36	0.30	0.011	21.42
	Mg	36	0.13	0.003	16.43
50	K	36	3.41	0.073	12.74
	Ca	36	0.32	0.013	25.19
	Mg	36	0.20	0.006	16.82
2	K	36	1.90	0.053	16.74
	Ca	36	0.30	0.009	18.65
	Mg	36	0.15	0.003	12.28
7	K	36	2.96	0.081	16.35
	Ca	36	0.35	0.011	19.14
	Mg	36	0.13	0.003	12.73
11	K	36	2.36	0.063	16.08
	Ca	36	0.31	0.011	22.37
	Mg	36	0.14	0.005	20.80
21	K	36	3.19	0.101	18.95
	Ca	36	0.40	0.015	23.15
	Mg	36	0.17	0.004	15.48
22	K	36	3.10	0.125	24.11
	Ca	36	0.39	0.012	18.16
	Mg	36	0.15	0.003	13.68
40	K	36	3.18	0.086	16.30
	Ca	36	0.25	0.006	14.17
	Mg	36	0.19	0.004	11.85
101	K	36	2.58	0.068	15.83
	Ca	36	0.33	0.016	28.62
	Mg	36	0.14	0.003	14.87
102	K	36	3.03	0.084	16.58
	Ca	36	0.34	0.009	16.25
	Mg	36	0.13	0.003	15.32

Appendix I. Summary statistics for cation concentrations (percent dry weight) in Smilicina trifolia

JULY, 1985

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	K	36	2.66	0.077	17.50
	Ca	36	0.44	0.017	23.09
	Mg	36	0.19	0.006	19.68
41	K	36	2.82	0.088	18.80
	Ca	36	0.34	0.013	22.44
	Mg	36	0.12	0.004	17.37
50	K	36	3.65	0.099	16.25
	Ca	36	0.40	0.014	21.22
	Mg	36	0.22	0.008	22.24
2	K	36	2.08	0.082	23.80
	Ca	36	0.42	0.012	17.65
	Mg	36	0.16	0.005	17.64
7	K	36	2.73	0.057	12.47
	Ca	36	0.44	0.009	11.97
	Mg	36	0.15	0.003	13.24
11	K	36	2.19	0.055	15.13
	Ca	36	0.41	0.013	18.71
	Mg	36	0.20	0.006	17.74
21	K	36	2.67	0.103	23.03
	Ca	36	0.58	0.025	25.91
	Mg	36	0.18	0.006	19.51
22	K	36	2.32	0.083	21.56
	Ca	36	0.49	0.015	17.90
	Mg	36	0.15	0.006	24.11
40	K	36	2.41	0.072	17.95
	Ca	36	0.29	0.009	18.73
	Mg	36	0.17	0.005	18.39
101	K	36	2.22	0.049	13.36
	Ca	36	0.39	0.015	24.09
	Mg	36	0.15	0.005	18.79
102	K	36	2.65	0.066	14.85
	Ca	36	0.41	0.009	13.24
	Mg	36	0.13	0.003	15.56

Appendix I. Summary statistics for cation concentrations (percent dry weight) in *Smilicina trifolia*.

AUGUST, 1985

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	K	36	2.19	0.069	18.99
	Ca	36	0.90	0.021	14.29
	Mg	36	0.28	0.011	22.82
41	K	36	3.11	0.098	18.87
	Ca	36	0.57	0.025	26.42
	Mg	36	0.17	0.005	17.44
50	K	36	3.01	0.071	14.11
	Ca	36	0.70	0.028	24.49
	Mg	36	0.28	0.013	28.90
2	K	36	1.95	0.095	29.22
	Ca	36	0.64	0.017	16.02
	Mg	36	0.21	0.006	17.23
7	K	36	2.52	0.058	13.35
	Ca	36	0.77	0.024	18.60
	Mg	36	0.18	0.006	20.37
11	K	36	1.69	0.060	21.23
	Ca	36	0.78	0.021	16.33
	Mg	36	0.28	0.013	28.90
21	K	36	2.30	0.073	18.99
	Ca	36	0.76	0.025	20.12
	Mg	36	0.22	0.007	19.12
22	K	36	2.08	0.069	19.89
	Ca	36	0.78	0.018	13.76
	Mg	36	0.19	0.007	21.14
40	K	36	2.28	0.084	22.06
	Ca	36	0.43	0.013	18.52
	Mg	36	0.20	0.008	22.68
101	K	36	1.91	0.058	18.33
	Ca	36	0.64	0.023	21.24
	Mg	36	0.22	0.008	22.42
102	K	36	2.25	0.072	19.24
	Ca	36	0.67	0.015	13.52
	Mg	36	0.14	0.006	26.06

Appendix I. Summary statistics for cation concentrations (percent dry weight) in Smilicina trifolia.

MAY, 1986

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	P	36	0.38	0.013	19.51
	K	36	3.42	0.062	10.94
	Ca	36	0.30	0.010	19.82
	Mg	36	0.17	0.004	12.98
	Mn	36	0.011	0.0006	32.12
41	P	36	0.59	0.020	20.11
	K	36	4.35	0.099	13.66
	Ca	36	0.31	0.011	21.01
	Mg	36	0.17	0.003	11.80
	Mn	36	0.014	0.0007	29.92
50	P	36	0.40	0.014	21.19
	K	36	4.28	0.095	13.36
	Ca	36	0.28	0.009	19.29
	Mg	36	0.19	0.003	9.99
	Mn	36	0.010	0.0005	29.51
2	P	35	0.41	0.013	18.37
	K	35	3.04	0.069	13.34
	Ca	35	0.23	0.009	24.30
	Mg	35	0.15	0.003	10.12
	Mn	35	0.018	0.001	36.70
7	P	36	0.58	0.011	10.95
	K	36	3.69	0.059	9.55
	Ca	36	0.28	0.008	17.72
	Mg	36	0.14	0.003	11.28
	Mn	36	0.02	0.0009	25.83
11	P	36	0.35	0.007	12.01
	K	36	2.78	0.042	9.16
	Ca	36	0.35	0.015	25.30
	Mg	36	0.15	0.004	15.33
	Mn	36	0.01	0.0007	28.40
21	P	36	0.57	0.013	13.57
	K	36	3.82	0.077	12.08
	Ca	36	0.41	0.014	20.15
	Mg	36	0.19	0.003	9.59
	Mn	36	0.01	0.001	42.17
22	P	36	0.42	0.014	20.21
	K	36	3.46	0.108	18.75
	Ca	36	0.35	0.012	20.57
	Mg	36	0.16	0.004	15.57
	Mn	36	0.01	0.0008	34.12

MAY, 1986 (Continued)

40	P	36	0.48	0.009	10.60
	K	36	3.74	0.073	11.77
	Ca	36	0.22	0.007	19.70
	Mg	36	0.18	0.002	8.02
	Mn	36	0.02	0.0008	24.95
101	P	36	0.38	0.009	14.45
	K	36	3.18	0.064	12.05
	Ca	36	0.34	0.015	25.72
	Mg	36	0.16	0.003	10.57
	Mn	36	0.02	0.0009	28.95
102	P	36	0.49	0.018	21.58
	K	36	3.80	0.076	12.00
	Ca	36	0.31	0.010	19.18
	Mg	36	0.16	0.003	11.77
	Mn	36	0.02	0.0008	28.19

Appendix I. Summary statistics for cation concentrations (percent dry weight) in <u>Smilicina trifolia</u>.

JUNE, 1986

BOG	VARIABLE	N	MEAN	STD ERR	CVE, 1986
20	P	36	.25	.005	11.76
	K	36	3.16	.095	18.03
	Ca	36	.48	.014	17.37
	Mg	36	.22	.006	16.25
	Mn	36	.02	.0007	24.96
41	P	36	.36	.013	22.10
	K	36	3.29	.102	18.51
	Ca	36	.38	.013	20.58
	Mg	36	.16	.005	17.37
	Mn	36	.02	.0008	30.40
50	P	36	.31	.011	21.80
	K	36	3.73	.088	14.17
	Ca	36	.43	.013	17.92
	Mg	36	.24	.006	15.97
	Mn	36	.02	.0007	27.56
2	P	36	.32	.012	22.00
	K	36	3.04	.107	21.04
	Ca	36	.44	.020	27.35
	Mg	36	.21	.005	14.54
	Mn	36	.03	.002	31.54
7	P	36	.44	.013	18.25
	K	36	3.24	.062	11.40
	Ca	36	.58	.027	27.92
	Mg	36	.20	.004	13.16
	Mn	36	.04	.002	32.99
11	P	36	.27	.005	10.16
	K	36	2.91	.079	16.06
	Ca	36	.62	.026	24.53
	Mg	36	.23	.008	20.63
	Mn	36	.03	.001	24.80
21	P	36	.38	.008	11.99
	K	36	3.15	.099	18.88
	Ca	36	.47	.015	19.45
	Mg	36	.18	.004	12.77
	Mn	36	.02	.0006	27.53
22	P	36	.25	.005	12.51
	K	36	2.85	.068	14.27
	Ca	36	.46	.011	14.41
	Mg	36	.16	.004	13.94
	Mn	36	.01	.0005	20.23

JUNE, 1986 (Continued)

40	P	36	.31	.008	14.52
	K	36	3.19	.080	14.54
	Ca	36	.39	.013	18.76
	Mg	36	.25	.006	13.26
	Mn	36	.03	.001	26.38
101	P	36	.29	.004	7.73
	K	36	2.59	.061	13.99
	Ca	36	.50	.022	25.70
	Mg	36	.22	.005	13.01
	Mn	36	.03	.001	28.33
102	P	36	.33	.009	17.31
	K	36	3.53	.079	13.36
	Ca	36	.51	.018	20.78
	Mg	36	.19	.004	11.78
	Mn	36	.03	.001	32.51

Appendix I. Summary statistics for cation concentrations (percent dry weight) in Smilicina trifolia.

JULY, 1986

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	P	36	.20	.003	9.82
	K	36	2.57	.067	15.72
	Ca	36	.66	.020	17.96
	Mg	36	.24	.009	21.71
	Mn	36	.02	.001	28.24
41	P	36	.26	.011	25.52
	K	36	2.45	.096	23.49
	Ca	36	.46	.018	23.62
	Mg	36	.16	.005	18.65
	Mn	36	.02	.001	31.25
50	P	35	.22	.007	18.56
	K	35	2.45	.077	15.37
	Ca	35	.60	.017	16.60
	Mg	35	.25	.007	16.47
	Mn	35	.02	.0009	27.11
2	P	36	.27	.010	21.22
	K	36	2.29	.081	21.25
	Ca	36	.55	.015	16.04
	Mg	36	.22	.005	14.23
	Mn	36	.04	.001	20.37
7	P	36	.36	.011	18.69
	K	36	2.37	.074	18.69
	Ca	36	.48	.017	20.89
	Mg	36	.16	.005	16.55
	Mn	36	.04	.002	27.61
11	P	36	.21	.002	6.63
	K	36	2.49	.075	18.11
	Ca	36	.72	.029	23.75
	Mg	36	.25	.009	22.06
	Mn	36	.04	.002	31.79
21	P	36	.33	.007	12.15
	K	36	2.89	.080	16.56
	Ca	36	.67	.023	20.78
	Mg	36	.21	.007	19.97
	Mn	36	.02	.001	29.11
22	P	36	.21	.005	13.09
	K	36	2.21	.065	17.51
	Ca	36	.65	.019	17.48
	Mg	36	.17	.007	23.51
	Mn	36	.02	.001	26.96

JULY, 1986 (Continued)

40	P	36	.24	.005	12.54
	K	36	2.22	.063	17.15
	Ca	36	.48	.018	21.84
	Mg	36	.26	.007	16.84
	Mn	36	.03	.001	26.85
101	P	36	.23	.005	12.79
	K	36	2.29	.076	19.95
	Ca	36	.72	.027	22.05
	Mg	36	.26	.006	14.81
	Mn	36	.04	.001	22.13
102	P	36	.21	.004	10.80
	K	36	2.50	.049	11.88
	Ca	36	.73	.024	19.74
	Mg	36	.19	.005	15.67
	Mn	36	.04	.001	24.09

Appendix I. Summary statistics for cation concentrations (percent dry weight) in <u>Ledum groenlandicum</u>.

JUNE, 1986

20	P	36	.15	.002	8.77
	K	36	.88	.021	14.06
	Ca	36	.42	.009	12.29
	Mg	36	.13	.002	10.81
	Mn	36	.07	.003	26.99
41	P	36	.17	.002	7.18
	K	36	.88	.012	8.46
	Ca	36	.47	.009	12.13
	Mg	36	.15	.003	13.21
	Mn	36	.05	.003	29.76
50	P	36	.16	.003	11.10
	K	36	.86	.015	10.74
	Ca	36	.39	.009	13.34
	Mg	36	.11	.003	14.81
	Mn	36	.06	.004	35.10
2	P	36	.17	.002	8.06
	K	36	.82	.017	12.37
	Ca	36	.52	.010	11.39
	Mg	36	.16	.003	11.42
	Mn	36	.07	.004	34.16
7	P	36	.17	.003	9.16
	K	36	.86	.019	13.00
	Ca	36	.46	.014	17.88
	Mg	36	.15	.003	11.21
	Mn	36	.06	.003	27.64
11	P	36	.17	.003	11.88
	K	36	.98	.020	12.13
	Ca	36	.37	.008	13.46
	Mg	36	.12	.002	11.76
	Mn	36	.09	.004	27.98
21	P	35	.15	.002	6.92
	K	35	.87	.014	9.47
	Ca	35	.39	.008	12.59
	Mg	35	.11	.003	14.16
	Mn	35	.06	.003	28.54
22	P	36	.19	.003	8.70
	K	36	.91	.016	10.21
	Ca	36	.45	.012	15.68
	Mg	36	.16	.004	15.00
	Mn	36	.06	.004	33.57

JUNE, 1986 (Continued)

40	P	36	.15	.003	11.27
	K	36	.82	.010	7.26
	Ca	36	.41	.008	11.97
	Mg	36	.14	.003	11.41
	Mn	36	.06	.002	25.63
101	P	36	.15	.002	7.18
	K	36	.92	.014	9.23
	Ca	36	.42	.009	12.97
	Mg	36	.13	.003	16.23
	Mn	36	.06	.003	33.44
102	P	36	.15	.003	12.03
	K	36	.88	.018	12.55
	Ca	36	.42	.010	13.85
	Mg	36	.13	.003	16.23
	Mn	36	.04	.003	49.20

Appendix I. Summary statistics for cation concentrations (percent dry weight) in *Ledum groenlandicum*.

JULY, 1986

BOG	Variable	N	Mean	Std Err	C.V.
20	P	36	.10	.002	10.29
	K	36	.63	.013	12.70
	Ca	36	.58	.012	12.60
	Mg	36	.15	.003	12.24
	Mn	36	.09	.005	31.29
41	P	36	.12	.002	7.86
	K	36	.53	.013	14.43
	Ca	36	.63	.014	13.84
	Mg	36	.16	.004	14.56
	Mn	36	.07	.003	26.20
50	P	36	.11	.002	11.37
	K	36	.53	.015	16.80
	Ca	36	.54	.018	20.06
	Mg	36	.13	.003	14.66
	Mn	36	.10	.007	40.74
2	P	36	.15	.004	14.81
	K	36	.75	.027	22.04
	Ca	36	.55	.016	17.03
	Mg	36	.17	.004	14.90
	Mn	36	.07	.004	33.21
7	P	36	.12	.001	7.73
	K	36	.57	.013	14.10
	Ca	36	.60	.014	13.88
	Mg	36	.16	.003	12.47
	Mn	36	.08	.003	25.98
11	P	36	.11	.003	17.08
	K	36	.67	.026	23.21
	Ca	36	.50	.013	16.04
	Mg	36	.13	.004	18.13
	Mn	36	.09	.006	42.42
21	P	36	.13	.004	17.84
	K	36	.57	.023	23.73
	Ca	36	.61	.016	15.77
	Mg	36	.17	.005	17.82
	Mn	36	.08	.004	27.75

JULY, 1986 (Continued)

22	P	36	.10	.003	15.20
	K	36	.58	.015	15.56
	Ca	36	.57	.011	11.43
	Mg	36	.14	.003	14.67
	Mn	36	.08	.004	30.33
40	P	36	.11	.002	12.81
	K	36	.59	.011	11.06
	Ca	36	.58	.017	17.07
	Mg	36	.16	.004	12.69
	Mn	36	.08	.004	26.40
101	P	36	.11	.002	13.47
	K	36	.71	.024	20.51
	Ca	36	.48	.016	19.60
	Mg	36	.14	.003	14.70
	Mn	36	.07	.004	33.90
102	P	36	.11	.003	16.25
	K	36	.73	.027	22.05
	Ca	36	.52	.015	17.09
	Mg	36	.13	.004	17.34
	Mn	36	.05	.005	55.92

Appendix I. Summary statistics for cation concentrations (percent dry weight) in *Ledum groenlandicum*.

September, 1986

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	P	36	.10	.001	7.96
	K	36	.46	.009	12.35
	Ca	36	.67	.017	14.99
	Mg	36	.16	.004	14.45
	Mn	36	.10	.008	45.94
41	P	36	.11	.001	7.60
	K	36	.46	.010	13.18
	Ca	36	.66	.016	14.21
	Mg	36	.16	.004	14.45
	Mn	36	.07	.005	41.63
50	P	36	.10	.002	9.32
	K	36	.45	.011	14.19
	Ca	36	.64	.022	20.73
	Mg	36	.14	.004	15.80
	Mn	36	.11	.008	43.93
2	P	36	.12	.002	12.18
	K	36	.52	.016	18.81
	Ca	36	.69	.014	11.98
	Mg	36	.17	.003	10.71
	Mn	36	.08	.005	34.62
7	P	36	.11	.002	9.71
	K	36	.48	.012	14.53
	Ca	36	.72	.016	13.77
	Mg	36	.17	.004	14.59
	Mn	36	.10	.004	24.64
11	P	36	.10	.002	11.41
	K	36	.49	.018	22.82
	Ca	36	.63	.016	15.26
	Mg	36	.15	.004	18.17
	Mn	36	.13	.006	29.82
21	P	36	.12	.003	12.73
	K	36	.48	.010	12.87
	Ca	36	.68	.013	11.75
	Mg	36	.17	.004	13.84
	Mn	36	.09	.004	28.22
22	P	36	.10	.002	9.03
	K	36	.50	.011	13.80
	Ca	36	.63	.017	16.22
	Mg	36	.14	.003	11.89
	Mn	36	.09	.004	29.83

SEPTEMBER, 1986 (Continued)

40	P	36	.11	.002	11.40
	K	36	.52	.014	16.25
	Ca	36	.59	.018	18.05
	Mg	36	.15	.004	13.87
	Mn	36	.07	.004	35.16
101	P	36	.10	.001	8.10
	K	36	.53	.013	14.48
	Ca	36	.58	.016	16.29
	Mg	36	.15	.004	14.58
	Mn	36	.08	.005	36.83
102	P	36	.10	.002	13.42
	K	36	.56	.011	12.22
	Ca	36	.57	.015	15.97
	Mg	36	.14	.004	15.66
	Mn	36	.05	.005	55.56

Appendix I. Summary statistics for cation concentrations (percent dry weight) in *Ledum groenlandicum*.

September, 1987

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	P	120	.10	.001	14.38
	K	120	.50	.008	16.86
	Ca	120	.61	.007	12.15
	Mg	120	.15	.002	12.15
	Mn	120	.09	.003	40.31
41	P	120	.10	.0007	7.24
	K	120	.46	.005	12.82
	Ca	120	.67	.006	10.55
	Mg	120	.16	.002	12.75
	Mn	120	.08	.002	28.98
50	P	120	.09	.0009	10.54
	K	120	.47	.006	13.09
	Ca	120	.59	.007	13.15
	Mg	120	.13	.002	15.64
	Mn	120	.10	.003	31.35
2	P	120	.10	.0008	9.24
	K	120	.49	.007	15.21
	Ca	120	.64	.009	15.54
	Mg	120	.15	.002	13.85
	Mn	120	.09	.003	32.68
7	P	120	.11	.0009	8.75
	K	120	.53	.007	14.72
	Ca	120	.65	.007	12.15
	Mg	120	.15	.002	13.52
	Mn	120	.08	.002	28.45
11	P	120	.09	.0009	11.37
	K	120	.46	.006	14.08
	Ca	120	.60	.008	14.91
	Mg	120	.14	.002	17.37
	Mn	120	.12	.004	34.25
21	P	120	.11	.0008	8.23
	K	120	.49	.006	13.19
	Ca	120	.62	.008	13.68
	Mg	120	.16	.002	15.25
	Mn	120	.08	.002	30.79
22	P	120	.08	.0007	9.24
	K	120	.49	.005	11.65
	Ca	120	.59	.006	10.58
	Mg	120	.13	.002	14.38
	Mn	120	.09	.003	31.70

SEPTEMBER, 1987 (Continued)

40	P	120	.10	.001	15.55
	K	120	.57	.008	16.14
	Ca	120	.57	.007	12.48
	Mg	120	.14	.002	13.08
	Mn	120	.07	.002	29.18
101	P	120	.09	.0008	9.83
	K	120	.52	.006	13.40
	Ca	120	.60	.007	12.49
	Mg	120	.15	.002	16.15
	Mn	120	.08	.003	41.37
102	P	120	.10	.001	11.47
	K	120	.55	.007	13.51
	Ca	120	.59	.006	11.49
	Mg	120	.14	.002	18.14
	Mn	120	.06	.003	50.42

Appendix I. Summary statistics for cation concentrations (percent dry weight) in <u>Picea mariana</u>.

SEPTEMBER, 1984

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	K	24	.55	.015	13.78
	Ca	24	.34	.017	24.77
	Mg	24	.11	.004	18.63
41	K	24	.61	.020	16.32
	Ca	24	.35	.019	26.85
	Mg	24	.08	.003	15.19
50	K	24	.57	.015	13.02
	Ca	24	.33	.020	29.88
	Mg	24	.097	.005	24.58
2	K	24	.59	.015	12.11
	Ca	24	.41	.017	20.70
	Mg	24	.09	.002	10.67
7	K	24	.62	.026	20.53
	Ca	24	.30	.021	34.03
	Mg	24	.09	.003	15.71
11	K	24	.47	.012	12.88
	Ca	24	.36	.021	28.70
	Mg	24	.09	.003	14.49
21	K	24	.59	.014	11.87
	Ca	24	.39	.015	18.43
	Mg	24	.11	.003	12.66
22	K	24	.57	.018	15.62
	Ca	24	.38	.017	21.75
	Mg	24	.11	.003	16.13
40	K	24	.55	.016	14.48
	Ca	24	.28	.015	26.64
	Mg	24	.08	.002	16.11
101	K	24	.49	.012	12.50
	Ca	24	.29	.015	25.05
	Mg	24	.09	.003	16.11
102	K	24	.53	.016	14.61
	Ca	24	.31	.016	24.64
	Mg	24	.08	.002	13.07

Appendix I. Summary statistics for cation concentrations (percent dry weight) in *Picea mariana*.

September, 1985

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	K	24	.53	.019	17.52
	Ca	24	.25	.020	38.33
	Mg	24	.08	.003	18.66
41	K	24	.60	.021	17.14
	Ca	24	.14	.008	27.81
	Mg	24	.04	.001	12.33
50	K	24	.55	.022	19.14
	Ca	24	.25	.017	33.59
	Mg	24	.09	.003	14.61
2	K	24	.50	.015	14.49
	Ca	24	.26	.013	25.21
	Mg	24	.07	.002	14.29
7	K	24	.57	.021	18.34
	Ca	24	.20	.008	20.74
	Mg	24	.07	.002	16.20
11	K	24	.40	.012	14.31
	Ca	24	.30	.018	29.78
	Mg	24	.08	.003	18.35
21	K	24	.55	.016	14.25
	Ca	24	.26	.013	24.82
	Mg	24	.08	.002	12.86
22	K	24	.51	.020	19.20
	Ca	24	.22	.011	23.76
	Mg	24	.07	.002	12.45
40	K	24	.52	.020	19.20
	Ca	24	.22	.011	23.76
	Mg	24	.07	.002	12.45
101	K	24	.43	.013	15.04
	Ca	24	.21	.011	24.76
	Mg	24	.07	.004	24.01
102	K	24	.44	.016	17.10
	Ca	24	.22	.014	29.88
	Mg	24	.07	.002	11.19

Appendix I. Summary statistics for cation concentrations (percent dry weight) in Ledum groenlandicum.

September, 1986

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	K	24	.54	.014	15.19
	Ca	24	.31	.014	26.83
	Mg	24	.10	.003	16.56
41	K	24	.60	.015	15.49
	Ca	24	.34	.016	27.21
	Mg	24	.09	.002	13.43
50	K	24	.54	.017	18.82
	Ca	24	.34	.018	32.26
	Mg	24	.09	.003	18.66
2	K	24	.57	.012	12.81
	Ca	24	.34	.011	19.99
	Mg	24	.09	.002	16.07
7	K	24	.58	.015	15.17
	Ca	24	.31	.016	30.87
	Mg	24	.09	.002	14.67
11	K	24	.48	.011	14.35
	Ca	24	.37	.016	25.50
	Mg	24	.10	.002	15.35
21	K	24	.59	.016	15.99
	Ca	24	.34	.013	23.15
	Mg	24	.09	.002	13.34
22	K	24	.55	.017	17.98
	Ca	24	.32	.013	24.82
	Mg	24	.09	.002	15.39
40	K	24	.57	.018	18.67
	Ca	24	.30	.015	30.77
	Mg	24	.07	.002	16.83
101	K	24	.49	.013	16.11
	Ca	24	.32	.015	27.81
	Mg	24	.08	.002	16.84
102	K	24	.51	.017	19.98
	Ca	24	.29	.014	29.45
	Mg	24	.08	.003	19.05

Appendix I. Summary statistics for cation concentrations (percent dry weight) in *Ledum groenlandicum*.

September, 1987

BOG	VARIABLE	N	MEAN	STD ERR	CV
20	P	36	.10	.002	9.55
	K	36	.66	.015	13.61
	Ca	36	.39	.020	31.50
	Mg	36	.11	.003	17.96
	Mn	36	.11	.004	23.99
41	P	36	.13	.002	9.46
	K	36	.72	.017	14.38
	Ca	36	.38	.018	28.26
	Mg	36	.10	.002	14.34
	Mn	36	.08	.003	20.42
50	P	36	.10	.001	8.02
	K	36	.61	.016	16.22
	Ca	36	.41	.020	29.18
	Mg	36	.11	.003	16.41
	Mn	36	.12	.004	21.92
2	P	36	.14	.003	11.50
	K	36	.70	.014	11.72
	Ca	36	.41	.015	22.24
	Mg	36	.11	.003	16.21
	Mn	36	.10	.004	24.61
7	P	36	.14	.003	14.70
	K	36	.71	.017	14.19
	Ca	36	.37	.017	27.39
	Mg	36	.11	.003	17.58
	Mn	36	.10	.004	22.00
11	P	36	.09	.001	9.06
	K	36	.53	.013	14.09
	Ca	36	.44	.018	25.03
	Mg	36	.11	.002	13.65
	Mn	36	.13	.006	26.01
21	P	36	.14	.003	13.43
	K	36	.69	.015	12.72
	Ca	36	.40	.015	22.52
	Mg	36	.11	.002	12.06
	Mn	36	.08	.003	23.99
22	P	36	.09	.001	8.76
	K	36	.60	.015	15.12
	Ca	36	.37	.018	28.33
	Mg	36	.11	.003	16.66
	Mn	36	.09	.003	20.89

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40	P	36	.12	.003	13.86
	K	36	.66	.021	18.52
	Ca	36	.32	.015	28.93
	Mg	36	.09	.003	18.08
	Mn	36	.08	.002	17.73
101	P	36	.10	.002	12.40
	K	36	.62	.016	15.80
	Ca	36	.35	.014	23.94
	Mg	36	.11	.003	15.46
	Mn	36	.09	.003	18.44
102	P	36	.10	.002	9.59
	K	36	.60	.015	15.16
	Ca	36	.34	.015	26.87
	Mg	36	.11	.003	16.21
	Mn	36	.09	.003	21.96

APPENDIX J. RESULTS OF THE NESTED ANALYSES OF VARIANCE FOR FOLIAR NUTRIENTS

Appendix J. Results of nested analyses of variance for foliar nutrients. Nested effects include ELF Bog Type, Bog nested within Type, and Plot nested within Bog.

Element	Source	df	SS	F	Sign. F
Smilacina trifoliata					
June, 1985					
K	Type	3	39.46	2.80	NS
	Bog	7	32.82	6.73	.0001
	Plot	55	38.31	4.05	.0001
	Error	330	56.77		
Ca	Type	3	0.055	0.11	NS
	Bog	7	1.128	9.39	.0001
	Plot	55	0.943	2.38	.0001
	Error	330	2.374		
Mg	Type	3	0.791	1.80	NS
	Bog	7	1.024	12.76	.0001
	Plot	55	0.630	3.53	.0001
	Error	330	1.071		
July, 1985					
K	Type	3	2.912	2.18	NS
	Bog	7	3.117	8.82	.0001
	Plot	55	2.777	3.23	.0001
	Error	330	5.153		
Ca	Type	3	0.131	0.15	NS
	Bog	7	2.111	19.43	.0001
	Plot	55	0.854	2.56	.0001
	Error	330	1.999		
Mg	Type	3	0.368	0.54	NS
	Bog	7	1.589	20.86	.0001
	Plot	55	0.599	1.77	.001
	Error	330	2.025		
August, 1985					
K	Type	3	34.575	2.31	NS
	Bog	7	34.994	14.42	.0001
	Plot	55	19.069	1.98	.0001
	Error	330	57.788		
Ca	Type	3	0.499	0.23	NS
	Bog	7	5.158	20.92	.0001
	Plot	55	1.937	2.60	.0001
	Error	330	4.470		

Appendix J continued

Mg	Type	3	0.733	0.72	NS
	Bog	7	2.363	15.81	.0001
	Plot	55	1.174	2.82	.0001
	Error	330	2.502		

May, 1986

P	Type	3	0.160	0.17	NS
	Bog	7	2.220	21.30	.0001
	Plot	55	0.819	3.91	.0001
	Error	329	1.251		
K	Type	3	0.589	2.03	NS
	Bog	7	0.676	13.88	.0001
	Plot	55	0.383	2.88	.0001
	Error	329	0.796		
Ca	Type	3	0.126	0.32	NS
	Bog	7	0.923	13.74	.0001
	Plot	55	0.528	2.65	.0001
	Error	329	1.192		
Mg	Type	3	0.079	7.77	.01
	Bog	7	0.024	3.12	.01
	Plot	55	0.060	4.49	.0001
	Error	329	0.080		
Mn	Type	3	0.0022	3.07	NS
	Bog	7	0.0017	5.17	.0001
	Plot	55	0.0026	2.41	.0001
	Error	329	0.0064		

June, 1986

P	Type	3	6.863	0.16	NS
	Bog	7	100.017	22.64	.0001
	Plot	55	34.718	3.56	.0001
	Error	326	57.827		
K	Type	3	8.391	0.75	NS
	Bog	7	26.252	8.38	.0001
	Plot	55	24.615	1.98	.0001
	Error	326	73.657		
Ca	Type	3	0.950	2.21	NS
	Bog	7	1.002	4.90	.0001
	Plot	55	1.605	3.30	.0001
	Error	326	2.880		
Mg	Type	3	0.088	0.15	NS
	Bog	7	1.380	22.43	.0001
	Plot	55	0.483	2.64	.0001
	Error	326			

Appendix J continued

Mn	Type	3	6.283	7.54	.01
	Bog	7	1.944	7.24	.0001
	Plot	55	2.109	3.44	.0001
	Error	326	3.636		

July, 1986

P	Type	3	0.236	0.67	NS
	Bog	7	0.824	26.28	.0001
	Plot	55	0.246	3.49	.0001
	Error	329	0.423		
K	Type	3	5.346	0.71	NS
	Bog	7	17.486	6.73	.0001
	Plot	55	20.428	2.23	.0001
	Error	329	54.851		
Ca	Type	3	0.482	0.97	NS
	Bog	7	1.157	16.64	.0001
	Plot	55	0.546	1.71	.01
	Error	329	1.913		
Mg	Type	3	0.037	0.03	NS
	Bog	7	2.514	26.08	.0001
	Plot	55	0.757	2.67	.0001
	Error	329	1.697		
Mn	Type	3	3.943	15.71	.01
	Bog	7	0.586	3.14	.01
	Plot	55	1.465	2.30	.0001
	Error	329	3.814		

Ledum groenlandicum

June, 1986

P	Type	3	0.014	0.87	NS
	Bog	7	0.037	8.90	.0001
	Plot	55	0.033	3.44	.0001
	Error	329	0.057		
K	Type	3	0.043	0.14	NS
	Bog	7	0.712	4.06	.001
	Plot	55	1.377	3.62	.0001
	Error	329	2.276		
Ca	Type	3	0.058	0.24	NS
	Bog	7	0.560	12.87	.0001
	Plot	55	0.342	2.10	.0001
	Error	329	0.976		

Appendix J continued

Mg	Type	3	0.017	0.50	NS
	Bog	7	0.078	19.43	.0001
	Plot	55	0.032	2.17	.0001
	Error	329	0.087		
Mn	Type	3	0.019	1.72	NS
	Bog	7	0.026	3.67	.01
	Plot	55	0.055	3.50	.0001
	Error	329	0.094		
July, 1986					
P	Type	3	0.018	0.83	NS
	Bog	7	0.051	19.34	.0001
	Plot	55	0.021	1.61	.01
	Error	329	0.078		
K	Type	3	7.318	3.31	NS
	Bog	7	5.163	5.67	.0001
	Plot	55	7.157	1.67	.01
	Error	329	25.709		
Ca	Type	3	0.451	3.10	NS
	Bog	7	0.339	4.30	.001
	Plot	55	0.620	1.54	.05
	Error	329	2.414		
Mg	Type	3	0.018	0.58	NS
	Bog	7	.074	12.74	.0001
	Plot	55	0.046	1.80	.001
	Error	329	0.152		
Mn	Type	3	0.034	3.30	NS
	Bog	7	0.024	2.08	NS
	Plot	55	.091	2.88	.0001
	Error	329	0.189		
September, 1986					
P	Type	3	1.215	0.89	NS
	Bog	7	3.198	9.97	.0001
	Plot	55	2.519	2.13	.0001
	Error	330	7.080		
K	Type	3	0.364	11.40	.01
	Bog	7	0.075	1.34	NS
	Plot	55	0.436	1.45	.05
	Error	330	1.800		
Ca	Type	3	0.462	3.47	NS
	Bog	7	0.310	2.25	.05
	Plot	55	1.081	2.42	.0001
	Error	330	2.686		

Appendix J continued

Mg	Type	3	0.014	0.95	NS
	Bog	7	0.035	5.70	.0001
	Plot	55	0.048	1.97	.001
	Error	330	0.148		
Mn	Type	3	0.077	2.00	NS
	Bog	7	0.089	4.95	.001
	Plot	55	0.142	3.09	.0001
	Error	330	0.275		

September, 1987

P	Type	3	0.0062	0.21	NS
	Bog	7	0.0699	12.74	.0001
	Plot	55	0.0431	9.24	.0001
	Error	1254	0.1064		
K	Type	3	0.383	1.33	NS
	Bog	7	0.672	4.18	.001
	Plot	55	1.264	8.02	.0001
	Error	1254	3.595		
Ca	Type	3	0.366	1.06	NS
	Bog	7	0.806	5.35	.0001
	Plot	55	1.184	3.98	.0001
	Error	1254	6.785		
Mg	Type	3	0.0027	0.04	NS
	Bog	7	0.140	11.18	.0001
	Plot	55	0.098	4.51	.0001
	Error	1254	0.498		
Mn	Type	3	0.125	1.41	NS
	Bog	7	0.208	7.43	.0001
	Plot	55	0.219	5.38	.0001
	Error	1254	0.926		

Chamaedaphne calyculata

June, 1985

K	Type	3	5.719	2.77	NS
	Bog	7	4.826	5.33	.0001
	Plot	55	7.114	2.96	.0001
	Error	330	14.422		
Ca	Type	3	0.058	0.08	NS
	Bog	7	1.744	5.94	.0001
	Plot	55	2.308	1.97	.001
	Error	330	7.015		

Appendix J continued

Mg	Type	3	2.906	3.54	NS
	Bog	7	1.913	3.45	.01
	Plot	55	4.360	2.81	.0001
	Error	330	9.311		
August, 1985					
K	Type	3	0.229	18.69	.001
	Bog	7	0.029	0.78	NS
	Plot	55	0.289	1.50	.05
	Error	330	1.157		
Ca	Type	3	0.103	0.25	NS
	Bog	7	0.976	4.64	.001
	Plot	55	1.655	2.87	.0001
	Error	330	3.457		
Mg	Type	3	0.022	1.92	NS
	Bog	7	0.026	4.62	.001
	Plot	55	0.045	3.65	.0001
	Error	330	0.074		
September, 1985					
K	Type	3	0.143	2.21	NS
	Bog	7	0.152	2.39	.05
	Plot	55	0.499	1.89	.001
	Error	330	1.582		
Ca	Type	3	0.432	1.44	NS
	Bog	7	0.701	2.14	NS
	Plot	55	2.573	3.91	.0001
	Error	330	3.954		
Mg	Type	3	0.124	0.62	NS
	Bog	7	0.465	5.36	.0001
	Plot	55	0.682	3.07	.0001
	Error	330	1.334		
June, 1986					
P	Type	3	0.0356	1.66	NS
	Bog	7	0.0500	3.99	.01
	Plot	52	0.0931	1.55	.05
	Error	312	0.3613		
K	Type	3	0.217	0.78	NS
	Bog	7	0.651	8.59	.0001
	Plot	52	0.563	1.75	.01
	Error	312	1.933		

Appendix J continued

Ca	Type	3	0.088	1.20	NS
	Bog	7	0.171	3.37	.01
	Plot	52	0.377	1.45	.05
	Error	312	1.555		
Mg	Type	3	0.015	1.65	NS
	Bog	7	0.021	4.99	.001
	Plot	52	0.032	3.43	.0001
	Error	312	0.055		
Mn	Type	3	0.0017	0.13	NS
	Bog	7	0.0299	8.22	.0001
	Plot	52	0.0270	1.23	NS
	Error	312	0.1321		

July, 1986

P	Type	3	0.077	1.17	NS
	Bog	7	0.154	16.07	.0001
	Plot	55	0.075	3.52	.0001
	Error	330	0.128		
K	Type	3	0.126	0.37	NS
	Bog	7	0.803	7.42	.0001
	Plot	55	0.851	2.89	.0001
	Error	330	1.764		
Ca	Type	3	0.313	0.99	NA
	Bog	7	0.738	6.51	.0001
	Plot	55	0.890	3.33	.0001
	Error	330	1.606		
Mg	Type	3	0.00059	0.04	NS
	Bog	7	0.03918	11.66	.0001
	Plot	55	0.02640	1.96	.001
	Error	330	0.08065		
Mn	Type	3	0.787	0.85	NS
	Bog	7	2.161	10.87	.0001
	Plot	55	1.563	2.27	.0001
	Error	330	4.140		

September, 1986

P	Type	3	0.0103	0.45	NS
	Bog	7	0.0537	22.32	.0001
	Plot	55	0.0189	1.30	NS
	Error	330	0.0870		
K	Type	3	0.134	1.64	NS
	Bog	7	0.192	4.15	.001
	Plot	55	0.362	1.96	.001
	Error	330	1.112		

Appendix J continued

Ca	Type	3	0.252	1.82	NS
	Bog	7	0.323	3.02	.01
	Plot	55	0.842	3.09	.0001
	Error	330	1.635		
Mg	Type	3	0.0068	0.53	NS
	Bog	7	0.0297	5.14	.001
	Plot	55	0.0453	2.02	.0001
	Error	330	0.1344		
Mn	Type	3	0.025	1.39	NS
	Bog	7	0.043	2.85	.05
	Plot	55	0.118	1.76	.01
	Error	330	0.402		

Picea mariana

September, 1985

K	Type	3	0.385	2.67	NS
	Bog	7	0.337	7.16	.0001
	Plot	55	0.370	1.40	.05
	Error	198	0.951		
Ca	Type	3	0.377	0.70	NS
	Bog	7	1.262	9.46	.0001
	Plot	55	1.047	1.25	NS
	Error	198	3.024		
Mg	Type	3	0.0023	0.16	NS
	Bog	7	0.0333	22.60	.0001
	Plot	55	0.0116	1.70	.01
	Error	198	0.0246		

September, 1986

K	Type	3	0.246	1.63	NS
	Bog	7	0.352	4.45	.001
	Plot	55	0.623	1.47	0.05
	Error	329	2.531		
Ca	Type	3	0.052	0.97	NS
	Bog	7	0.126	1.73	NS
	Plot	55	0.570	1.40	.05
	Error	329	2.435		
Mg	Type	3	0.0074	1.98	NS
	Bog	7	0.0087	4.63	.001
	Plot	55	0.0147	1.40	.05
	Error	329	0.0629		

Appendix J continued

September, 1987

P	Type	3	106.718	0.29	NS
	Bog	7	856.235	81.82	.0001
	Plot	55	82.220	1.65	.01
	Error	330	299.387		
K	Type	3	0.126	0.27	NS
	Bog	7	1.075	12.79	.0001
	Plot	55	0.660	1.40	.05
	Error	330	2.828		
Ca	Type	3	0.217	2.12	NS
	Bog	7	0.238	3.22	.01
	Plot	55	0.580	1.01	NS
	Error	330	3.454		
Mg	Type	3	0.0016	0.48	NS
	Bog	7	0.0077	3.06	.01
	Plot	55	0.0197	1.29	.05
	Error	330	0.0917		
Mn	Type	3	0.870	1.79	NS
	Bog	7	1.131	13.24	.0001
	Plot	55	0.671	1.42	.05
	Error	330	2.844		